Dynamic Modeling of a Mobile Air Conditioning Compressor and Condenser from Actual Performance Data

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CHAPTER 1

INTRODUCTION

Objectives

Continuing environmental concerns have prompted automobile manufacturers to concentrate research and design efforts on smaller, lighter, more economic automobile designs. Ultimately, the manufacturers would like to provide more efficient automobiles without sacrificing performance and passenger comfort systems including air conditioning.

The increased use of microprocessors in automotive applications provides an opportunity to employ advanced adaptive and optimal control algorithms to improve overall air conditioning system performance. The efficiency of the system can be improved by optimizing the power consumption of the system components while still maintaining the overall passenger compartment cooling capabilities.

Mobile air conditioning systems differ from other systems because they operate in mostly transient conditions. Frequent fluctuations occur in the engine speed, passenger compartment air temperature, evaporator and condenser air flow rates, and outdoor air temperature. The compressor also cycles on and off to help prevent evaporator frosting.

The objective of this study is to develop a simple empirical model of the compressor and condenser. This model would be used in the development of advanced adaptive and optimal strategies for controlling the compressor displacement, expansion valve position, and evaporator and condenser fan speeds to improve the efficiency of the air conditioning system.

Background

The mobile air conditioning empirical modeling facility is part of the Air Conditioning and Refrigeration Center (ACRC) at the University of Illinois at Urbana-Champaign. The experimental facility was initially designed by Michael (1989). The original facility used manual data acquisition and also was not able to simulate many of the transient operating conditions that may be experienced by a mobile air conditioning system.

The facility was upgraded by installing computerized data acquisition and the associated instrumentation and establishing continuous air flow rate controls. These additions made it possible to collect transient data from the system and to simulate a larger range of operating conditions.

CHAPTER 2

LITERATURE REVIEW

Introduction

A large amount of literature exists on the analysis of transient vapor-compression cycles. The previous research includes both analytical and experimental models of components and entire systems. This literature provides background knowledge which is valuable to the present work. It also provides insights into modeling for both steady state and transient applications and explains techniques utilized in previous studies. The goal of the present study is to develop simple transient empirical models for the compressor and condenser of an automotive air conditioning system. These models will be useful in developing optimal and adaptive control strategies which require knowledge of the system dynamics.

Steady State Models

Ellison, Creswick, Rice, Jackson, and Fisher (1979) developed a system model of a heat pump based solely on physical principles. The paper contains useful suggestions on component and system modeling and experimental results to support the model.

Davis and Scott (1976) describe a steady-state model to evaluate off-design conditions, optimize component performance, and estimate effects of different refrigerants. Low computing time was accomplished with models based on fundamental principles coupled with carefully chosen empirical parameters based on relatively simple component testing.

Davis, Chianese, and Scott (1972) outline the basic theory and techniques used to develop the Air-Conditioning Analytical Simulation Package (A/CASP). The results of the model are also incorporated into a vehicle pull-down simulation. All of the models are compared and necessary parameters are adjusted to assure model accuracy to system tests.

Dhar and Soedel (1979) developed a similar program to model the transient behavior of a window air conditioner and a heat pump. Their simulation is also a combination of fundamental principles and empirical parameters.

Transient Models

MacArthur (1984) developed a transient heat pump model based entirely on fundamental principles. No experimental tests were performed to validate the model against actual system performance.

Mitsui (1988) modeled the start-up transients using fundamental differential equations solved by Euler's method. The results of this study were used in the development of a PID controlled expansion valve. Superheat and compressor speed were used in the controller to determine the expansion valve position. The new valve was successful in increasing the efficiency of the system during the start-up operation.

Crawford and Woods (1985) developed a procedure for deriving dynamic system models from actual building performance data. An autoregressive least squares technique was used to determine a model for temperatures of a single-family residence. Statistical methods were used to determine the model coefficients and the significance of each variable. Indoor dry bulb temperature and mean radiant temperature were predicted with standard deviations of 0.164°C and 0.203°C, respectively.

Shirey (1987) used the same modeling technique to develop residential heat pump models. Both the heating and cooling operational modes of the system were investigated. The standard deviation of the models were 0.15°F for heating operation and 0.19°F for cooling operation.

Modeling Technique Selection

The objective of this study is to develop models for an automotive air conditioning system. Since this type of system is subjected to frequent fluctuations in the operating conditions the steady-state model forms can not be applied directly. Most of the transient models that have been developed require the solution of differential equations either by Euler's method or Runge-Kutta integration. Both of these methods require a large amount of computation. The autoregressive technique described by Crawford and Woods provides a means to develop accurate dynamic models without solving any differential equations which greatly reduces the computation time. This type of model could be used to predict system transients quickly and could be easily incorporated into a microprocessor based controller.

CHAPTER 3

TEST STAND FOR TRANSIENT EMPIRICAL MODELING

Introduction

This chapter describes the test stand (Michael 1989) to perform transient studies of an automotive air conditioning system and components. The system was designed around a factory air conditioning system of a 1989 Chrysler K car. All of the components were production pieces with the exception of the evaporator and the thermostatic expansion valve. A plate/fin evaporator was used instead of the production tube and fin evaporator. The production thermostatic expansion valve was modified to allow manual control of the valve position. A description of the instrumentation and data acquisition of the test stand also appear in this chapter. Included in this description are the pressure, temperature, relative humidity, air flow rate, and refrigerant mass flow rate instrumentation. This test stand is located in the Air Conditioning and Refrigeration Center laboratory on the second floor of the Mechanical Engineering Laboratory.

Test Stand

A schematic diagram of the stand appears in Figure 3.1. The purpose of this facility was to perform transient empirical modeling of the system and its components. The stand was originally designed by Michael, and a description of most of the hardware used to construct the test facility can be found in Michael (1989). Significant modifications have been made to the condenser air loop, evaporator air loop, thermostatic expansion valve, and various instrumentation since the original test stand was constructed. These changes are described in the following sections

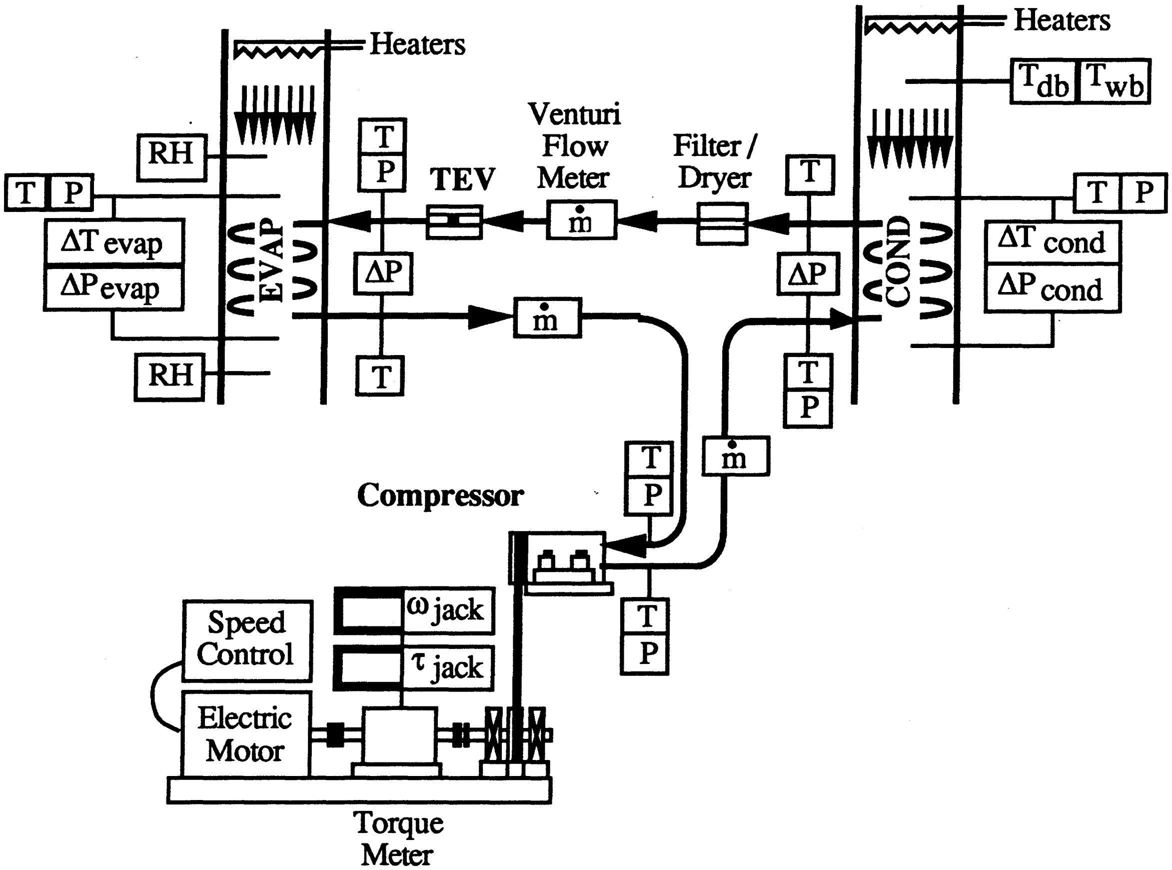

Figure 3.2. Test Stand Schematic.

Condenser Air Loop

The condenser air loop consisted of the condenser fan, condenser, inlet ducting, and an inlet air heater.

The condenser fan motor speed was varied using a Lambda 0-20V regulated power supply (Model No. LK-350-FM0V). This allowed variable condenser air flow rate control from 0 to 1400 scfm.

A sheet metal inlet duct 36" (0.91 m) in length of varying cross section was placed in front of the condenser and attached to the sheet metal box housing the condenser. The inlet air heater was placed in this duct. The duct also provided a suitable environment for the development of the condenser air flow rate map which is described later in this chapter.

Recently, a heater was added to the inlet ducting. Temperature control schemes for the heater are being investigated. The heater was not used in any of the tests for this study.

Evaporator Air Loop

The evaporator blower speed was controlled using a Lambda 0-20V regulated power supply (Model No. LK-350-FM). This allowed variable evaporator air flow rate control from 0 to 300 scfm.

Ducting was attached to the evaporator housing unit to provide the pressure drop that ensured proper operation of the blower. The ducting attached was a fabricated sheet metal duct 12" in length. Similar to the condenser, this duct also provided a suitable environment for the development of an evaporator air flow rate map.

Thermostatic Expansion Valve

The production TEV controlled the amount of refrigerant released into the evaporator to ensure that the refrigerant leaving the evaporator was completely evaporated. The TEV does this by monitoring the outlet state of the evaporator and automatically adjusting a valve that controls the amount of refrigerant released. In the course of collecting preliminary transient data, it was determined that the cyclic nature of the TEV was corrupting the crisp transients of the system. Therefore, the refrigerant charged power head of the TEV was replaced with an uncharged power head which was connected to a pressurized air tank. This allowed the position of the valve to be set with a specific pressure that was held constant during the course of a test as the transient system responses were collected.

Instrumentation

The test stand was fitted with instrumentation to allow data to be taken for the transient empirical studies. Fast response time was crucial for all instrumentation components so the transients could be recorded. The following sections describe the instrumentation and data acquisition of the test stand. Figure 3.1 shows the type and location of data taken from the stand.

Temperature Instrumentation

Temperature instrumentation was required to determine air temperatures and refrigerant temperatures. The inlet air temperatures of both the condenser and evaporator were measured using a fabricated copper-constantan thermocouple circuit. Four thermocouples were placed downstream of each of the heat exchangers and wired in parallel to obtain an average inlet air temperature.

The outlet air temperatures were measured using a nine point thermocouple array (Kempiak 1989). By setting up a series of sensing and reference junctions, an average temperature difference across the heat exchanger was measured. This temperature difference was then added or subtracted from the inlet air temperatures to obtain the outlet air temperature.

The refrigerant temperatures were measured using Omega 3" (7 cm) long thermocouple probes (Model No. TB-CPSS-116U). The thermocouple probes were copper-constantan with a 1/16" (1.6 mm) 306 stainless steel sheath. The thermocouple probes were mounted into a "T" in the refrigerant line with a compression fitting.

Pressure Instrumentation

Pressure instrumentation was required to determine air pressures and refrigerant pressures. The only ambient pressure required was an absolute pressure of the ambient air. This pressure was necessary to convert the gauge refrigerant pressure transducer outputs to absolute pressures. This measurement was determined using a Princo Mercurial NOVA barometer (Model No. 469) located on the second floor of the Mechanical Engineering Laboratory.

Refrigerant pressures were determined using a combination of gauge and differential pressure transducers. The outlet refrigerant pressure of the compressor and the inlet refrigerant pressure of the condenser were measured using two Setra gauge pressure transducers (Model No. 207) with a range of 0 to 500 psig (0 to 3447 kPa gauge). The output of these transducers is linear with pressure and ranges from 0.1 to 5.1 VDC. They have a dynamic response time of 1 to 5 ms. Their accuracy is ±0.13 per cent of full scale.

The inlet refrigerant pressure of the compressor and the inlet refrigerant pressure of the evaporator were measured using two Setra gauge pressure transducers (Model No. 207) with a range of 0 to 100 psig (0 to 689 kPa gauge). The pressure transducer characteristics are the same as those described above.

The refrigerant pressure drop across the condenser and the pressure drop across the evaporator were measured using two Setra high accuracy differential pressure transducers (Model No. 228-1) with a range of 0 to 25 psid (0 to 172 kPa differential). The output of the transducers is linear with pressure and ranges from 0 to 5 VDC. They have a dynamic response time of less than 40 ms. Their accuracy is ±0.15 per cent of full scale.

A 24 VDC, 2.4 ampere power supply was purchased to provide the voltage for all of the transducers. All of the pressure transducers were mounted on a separate "Unistrut" stand to minimize vibrations, and were connected to the various measurement points by 0.064" I. D. capillary tube with compression fittings

Condenser and Evaporator Inlet Air Flow Instrumentation

A map of the condenser inlet air velocity versus pressure drop was generated with a resistance temperature detector (RTD) velocity probe. A Sierra heated element velocity probe (Model No. AVS-600) with a range of 0 to 2000 ft/min (0 to 10 m/s) and an accuracy of 2 percent of full scale was used for the measurements. Compensating circuitry within the transducer provided a linear 0 to 5 VDC output with standard air velocity. This output was connected to a data acquisition channel until a flow map was developed and then it was removed.

The velocity pressure of the condenser air flow and the evaporator air flow was measured using two Setra very low differential pressure transducers (Model No. 264) with a range of 0 to 0.25 inches water column differential for the condenser and 0 to 2.5 inches water column differential for the evaporator. The output of the transducers is linear with pressure and ranges from 0 to 5 VDC. They have a dynamic response time of 1 to 5 ms. Their accuracy is ±1.0 per cent of full scale. The air flow pressure transducers were powered by the same power supply as the previous pressure transducers. Both transducers were mounted on the pressure transducer stand. A schematic of the condenser and evaporator air pressure measurement locations are shown in Figure 3.2 and Figure 3.3, respectively.

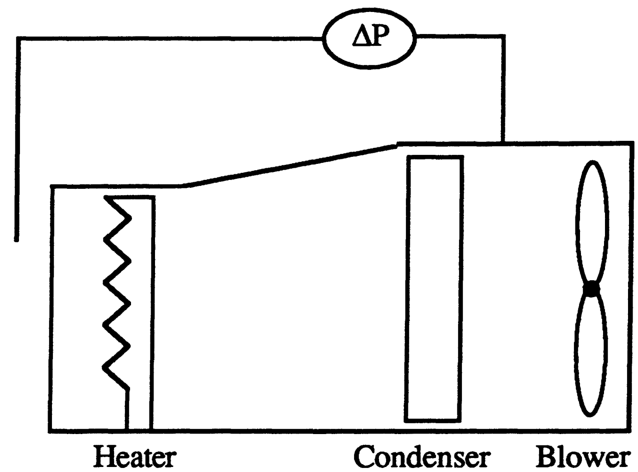

Figure 3.2. Condenser Pressure Drop Measurement.

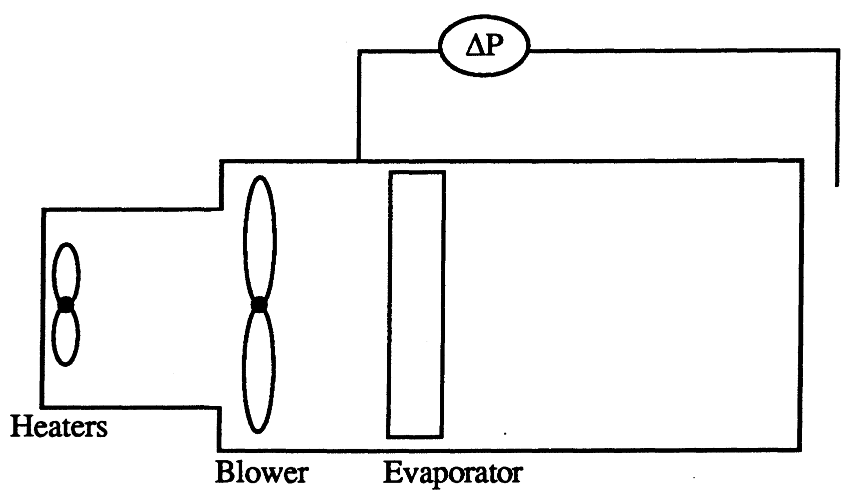

Figure 3.3. Evaporator Pressure Drop Measurement.

The Setra probe was inserted into holes in the inlet duct of the condenser and evaporator to obtain a mapping of the inlet air velocity versus the pressure drop across the heat exchanger. The map for the condenser and evaporator are shown in Figures 3.4 and 3.5, respectively. These flow maps were then used to generate smooth curves that related the volumetric air flow rate to the pressure drop. While recording transient data, only the pressure drop measurement was recorded. The curve equations were used in the Data Reduction Program (Appendix A) to convert the pressure drop measurements to their corresponding flow rate.

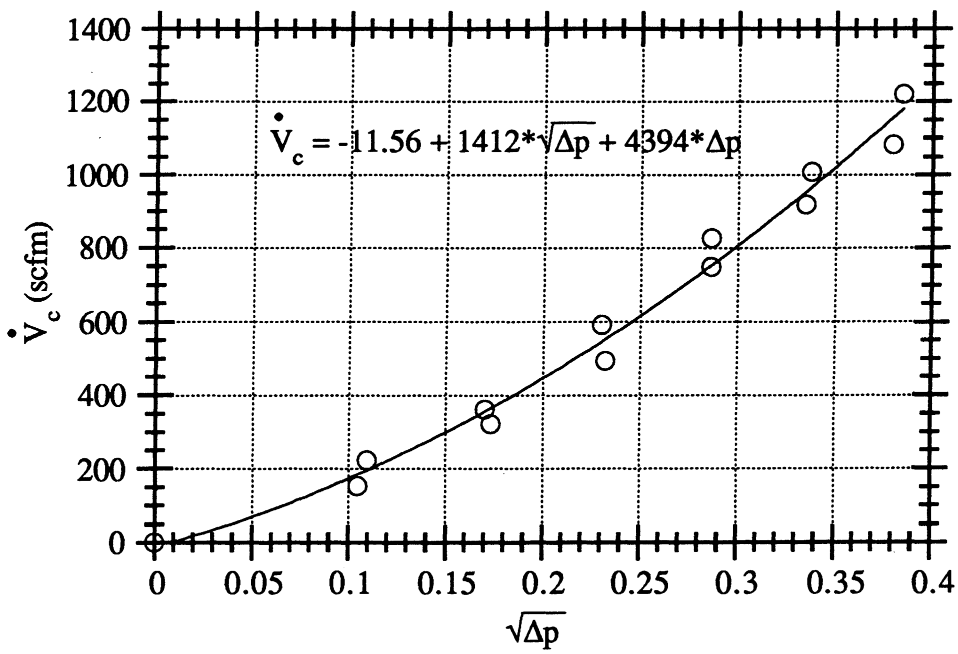

Figure 3.4. Condenser Flow Rate, ($\dot{V}_c$) vs. Pressure Drop, (Δp) Map.

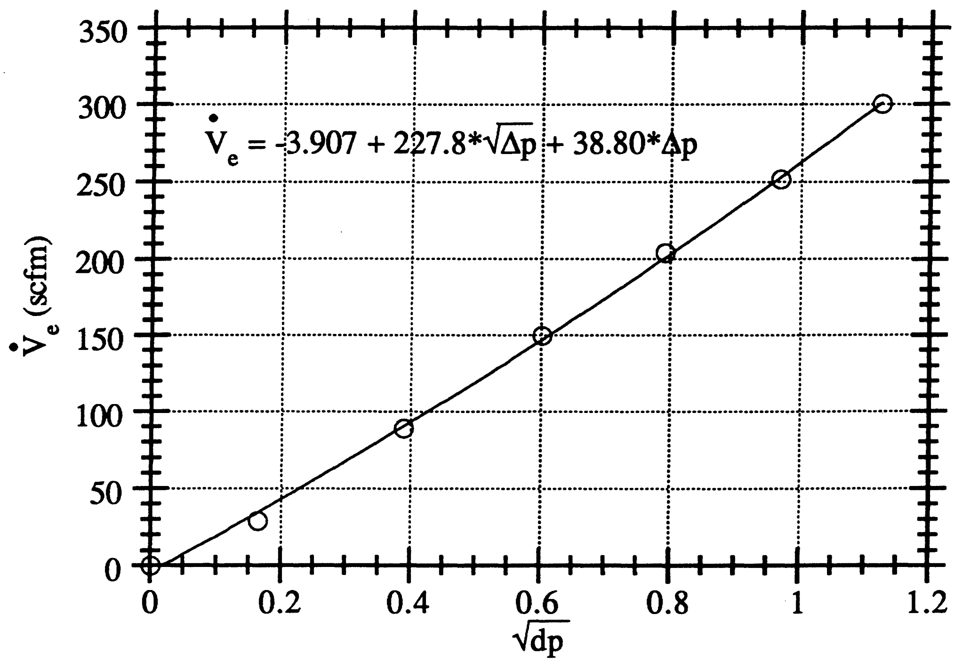

Figure 3.5. Evaporator Flow Rate, ($\dot{V}_e$) vs. Pressure Drop, (Δp) Map.

Relative Humidity Instrumentation

The relative humidity of the ambient lab air was measured indirectly using wet-bulb and dry-bulb thermocouples placed in the condenser inlet air stream. The wet and dry bulb temperatures were used to determine the relative humidity and humidity ratio of the ambient air from a psychrometric chart curve fit in the Data Reduction Program, (Appendix A).

The relative humidity of the inlet and outlet evaporator air was measured using two Rotronic Hygromer™ capacitive relative humidity sensors (Model No. HT220R) with a range of 0 to 100% relative humidity. The output of the transducers is linear with humidity and ranges from 0 to 5 VDC. Their accuracy is ±2.0% relative humidity.

Refrigerant Flow Rate Instrumentation

The refrigerant mass flow rate was measured at the compressor inlet (suction flow rate), the compressor outlet (discharge flow rate), and the TEV inlet (liquid line flow rate). The venturi flow meters were calibrated using the mass flow meter calibration facility. Maps were produced that quantified the relationship between the pressure drop across the venturi and the mass flow rate. These map equations were implemented in the Data Reduction Program.

Data Acquisition

All measurements were sent to the data acquisition boards located in the expansion slots of an Apple Macintosh II™ personal computer. The computer in tandem with the software supplied with the boards allowed for the display, output, storage, and analysis of the data. Three boards were purchased and satisfied the data acquisition needs of the test stand.

A Strawberry Tree 16-bit data acquisition board (Model ACM2-16-16) along with two T-21 thermocouple panels was used to read the thermocouple inputs. The data acquisition board and the thermocouple panels were purchased as a matched pair. The data acquisition board has 16 differential analog inputs and 16 digital input/outputs. Each thermocouple panel provided terminals for attaching the 16 different analog input and 16 digital input/outputs. Each panel can accept eight thermocouple inputs.

Two Strawberry Tree 12-bit data acquisition boards (Model ACM2-12-8A) along with two T-21 general purpose panels were used to read the other analog inputs from the test stand. The data acquisition board and the general purpose panels were purchased as a matched pair. The data acquisition board has 8 analog inputs, 8 digital input/outputs and two analog outputs. The general purpose panels provide the terminals for attaching the 8 analog inputs, 8 digital input/outputs and two analog outputs. The relative humidity sensors and all of the pressure transducers were attached to the two general purpose panels. The two analog output capabilities of each board were unused.

The data were acquired using the WorkBench™ software purchased from Strawberry Tree. The software displayed the data in real time on the screen and also sampled all of the data at predetermined time intervals and stored these data in a comma delimited text file. This file was then read by the Data Reduction Program, and numerous refrigerant and air-side properties were calculated for use in the model development programs.

CHAPTER 4

MODEL DEVELOPMENT TECHNIQUE

Introduction

This chapter describes the model development procedure and the modeling program. A brief description of the autoregressive least squares technique is presented. The data reduction program is also described.

Model Development

The method used to develop the transient compressor and condenser models was based on that developed by Crawford and Woods (1985). Their technique was used to develop dynamic system models from actual performance data from the system. The basis of this technique is a general linear model form:

$$y(k) = \mathbf{b}'_{\mathbf{n}}\mathbf{x}_{\mathbf{n}}(k) + e_n(k)$$

where:

$y(k)$ = predicted scalar variable

$\mathbf{b}_{\mathbf{n}}$ = vector of model coefficients

$\mathbf{x}_{\mathbf{n}}$ = vector of independent variables

e_n = model error at each time step

The vector $\mathbf{x}_{\mathbf{n}}$ can consist of previous dependent values, y(k-i), and any combination of independent variables. Using a least squares regression the coefficients are determined from the dependent and independent variables by minimizing the error over a given time interval. A number of substitutions are performed to alleviate the time consuming inversion of a large matrix in order to solve for the coefficients. A detailed description of the autoregressive least squares procedure and these substitutions is given in Schenk (1991).

Crawford and Woods used two statistics to determine a variables significance to the model under development. The t-statistic can be used at any point in the modeling process for any variable in the model.

$$t = \frac{b_{ni}(k_f\text{-}n)}{SSE_n W_{n-1}^{-1}(i,i)}$$

The F-statistic is only meaningful for the variable being added to a current model. It evaluates the variable by the effect it has on the relative sum of the squared error of the model.

$$F = \frac{(SSE_n - SSE_{n+1})(k_f - n - 1)}{SSE_{n+1}}$$

A detailed description of the use of these statistics is given by Schenk (1991).

Component Model Developer

Schenk wrote a program to implement the modeling procedure described previously. This program was modified to include localized variables that were significant to the compressor and condenser models. The Component Model Developer is a modification of the System Model Developer (Schenk 1991). Version 1.c of the Component Model Developer appears in Appendix B. The program is written in TrueBasic™ and determines the coefficients of the model variables from the system performance data.

The operation of the Component Model Developer is very similar to the System Model Developer. The program is very user friendly and detailed instructions about the operation of the program can be found in Schenk (1991).

Data Reduction Program

The Data Reduction Program (Schenk 1991) was written to verify the proper operation of the system. In this program the raw data collected from the test stand was used to calculate air-side and refrigerant-side properties that were not directly measured. Also incorporated in this program were the air flow maps and mass flow maps that were described in Chapter 3. The output from this program was used in by the model developer programs. Once again this program was modified to include the calculation of localized variables that were of interest in the compressor and condenser models. Version 2.d of the Data Reduction program appears in Appendix A.

CHAPTER 5

MODEL DETERMINATION

Introduction

The objective of this study was to develop models for the compressor power ($\dot{W}$), compressor inlet volumetric flow rate ($\dot{V}$) and the condenser inlet pressure (P_c). The compressor power and compressor inlet volumetric flow rate were functions of compressor speed (N), compressor inlet specific volume (υ), and the compressor discharge pressure to suction pressure ratio (R). The condenser inlet pressure was a function of condenser air flow rate ($\dot{V}_c$), condenser inlet mass flow rate ($\dot{m}$), and the condenser inlet refrigerant temperature (T_{rci}). The independent variables were perturbed by changing three global system variables: compressor speed (N), condenser air flow rate ($\dot{V}_c$), and evaporator inlet air temperature (T_{ei}).

In an actual mobile air conditioning system, the condenser air inlet temperature and evaporator air flow rate also experience fluctuations. The test facility did not have provisions for changing the condenser inlet air temperature, so its effect could not be studied. The evaporator housing contained heaters to vary the inlet air temperature. At the time when data were collected the heaters needed to be used to provide ambient air temperatures high enough to prevent evaporator frosting. Because no temperature controller was available on the heaters, the evaporator air flow rate could not be changed independently of the inlet air temperature. Therefore, when a transient was induced in the evaporator air flow rate, the evaporator inlet air temperature also changed creating interactions in the system transients that could not be easily distinguished. Because of this interaction the effect of evaporator air flow rate was not investigated.

Test Plan

The test plan was to first collect data sets in which only one global independent variable was changed and the others were held constant. This made the dynamics of the system very clear so that a suitable model form could be easily determined. Nonlinearities were exposed by stepping each of the independent variables through a series of induced transients. Each step was run long enough for the system to reach steady-state conditions.

The first dependent parameter investigated was evaporator inlet air temperature. The test was run by stepping the evaporator inlet air temperature up and down from 80°F to 102°F in approximately 11°F steps. These conditions corresponded to heater settings of: low-low, low-hi, and hi-hi. The compressor speed and condenser air flow rate were held constant (Figures 4.1, 4.2)

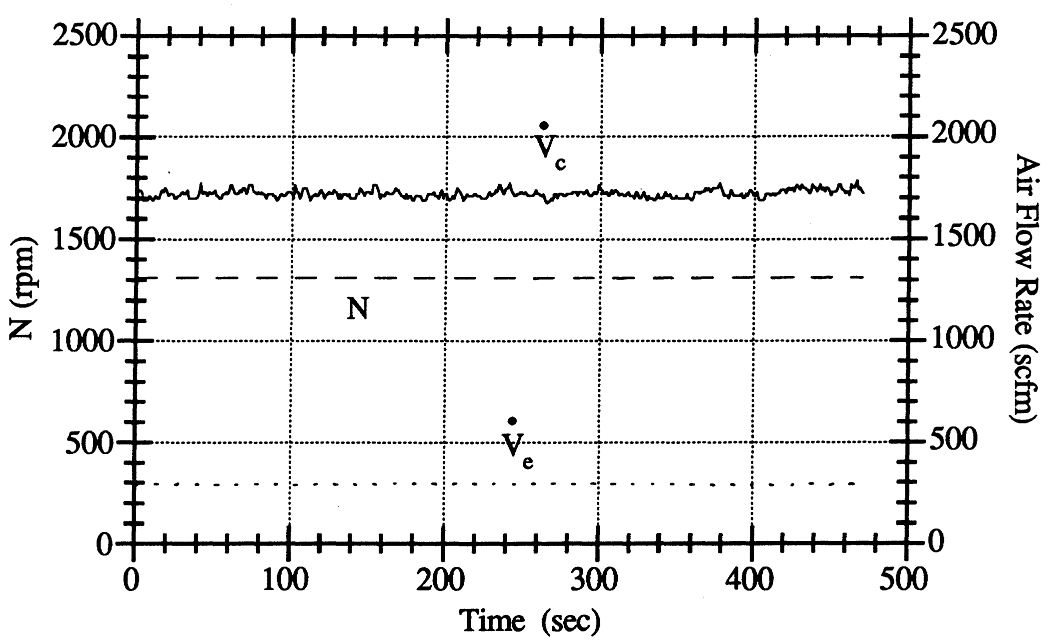

Figure 4.1. Test 1 - Compressor Speed and Condenser and Evaporator Air Flow Rates.

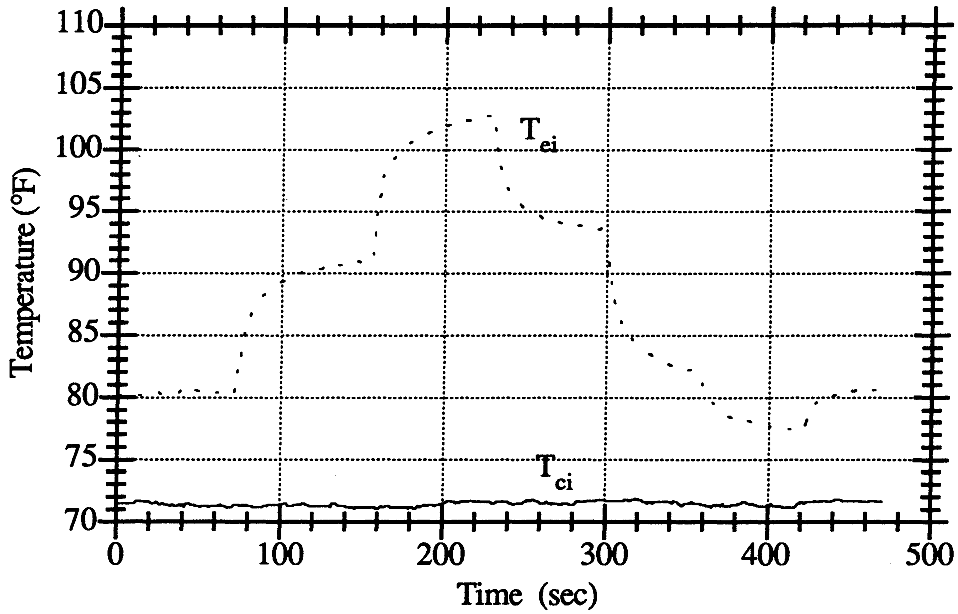

Figure 4.2. Test 1 - Evaporator and Condenser Inlet Air Temperatures.

The second test investigated the effect of condenser air flow rate. The condenser air flow rate was changed between 600 and 1700 scfm with intermediate steps at approximately 1000 and 1300 scfm. The compressor speed and evaporator inlet air temperature were held constant. (Figures 4.3, 4.4)

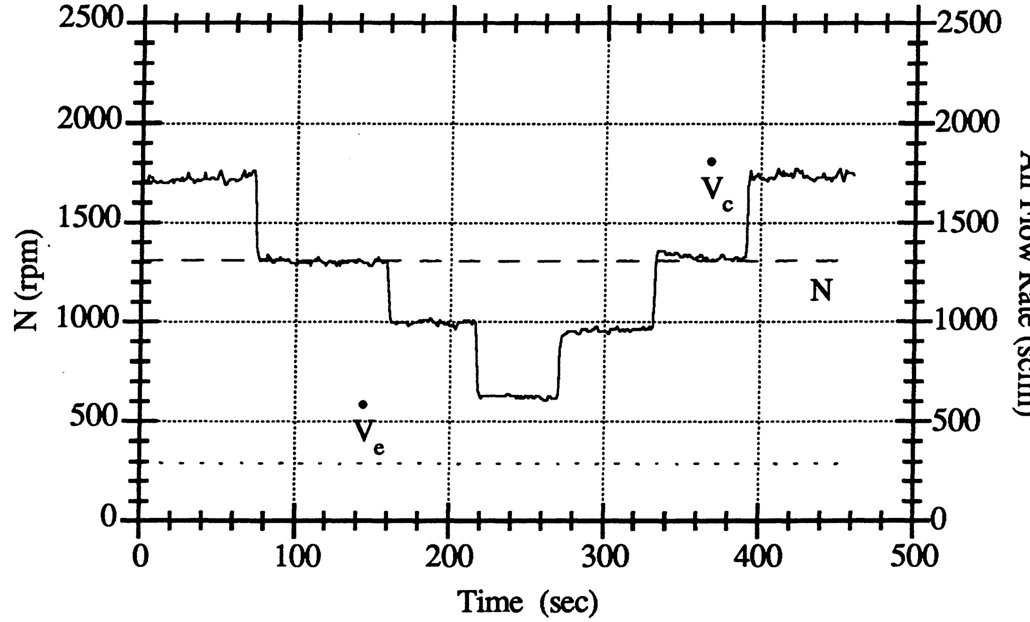

Figure 4.3. Test 2 - Compressor Speed and Condenser and Evaporator Air Flow Rates.

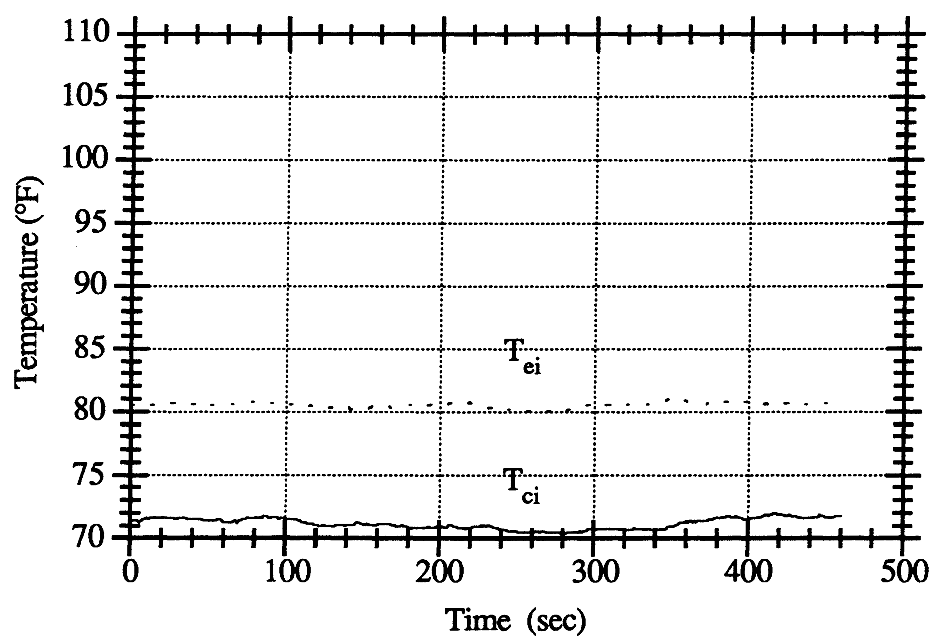

Figure 4.4. Test 2 - Evaporator and Condenser Inlet Air Temperatures.

The third test investigated the effect of compressor speed. The compressor speed was changed between 800 and 2300 rpm with intermediate steps at 1300 and 1800 rpm. The condenser air flow rate and evaporator inlet air temperature were held constant (Figures 4.5, 4.6).

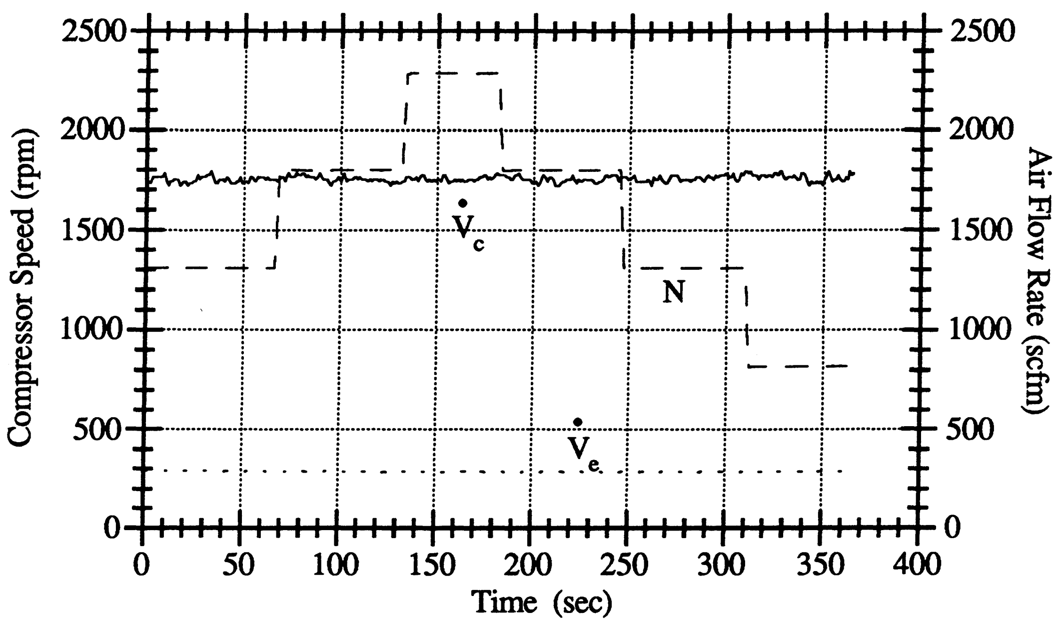

Figure 4.5. Test 3 - Compressor Speed and Condenser and Evaporator Air Flow Rates.

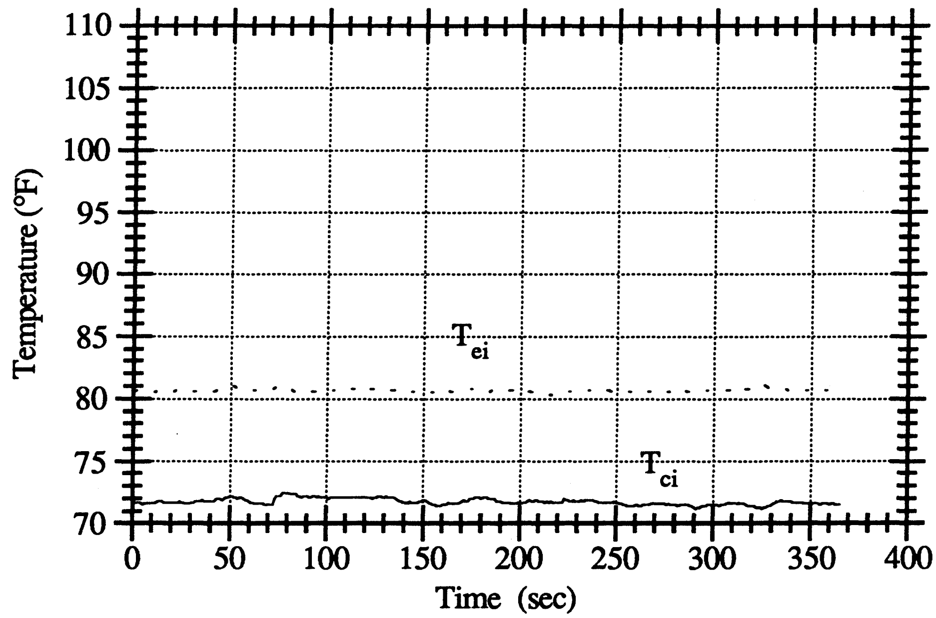

Figure 4.6. Test 3 - Evaporator and Condenser Inlet Air Temperatures.

Data were then collected in which all of the global independent variables were perturbed in a single test (test 4). This provided a suitable environment to model interactions between the various transients and provide a more accurate model form for the dependent variable performance as it might actually occur in a mobile air conditioning system.

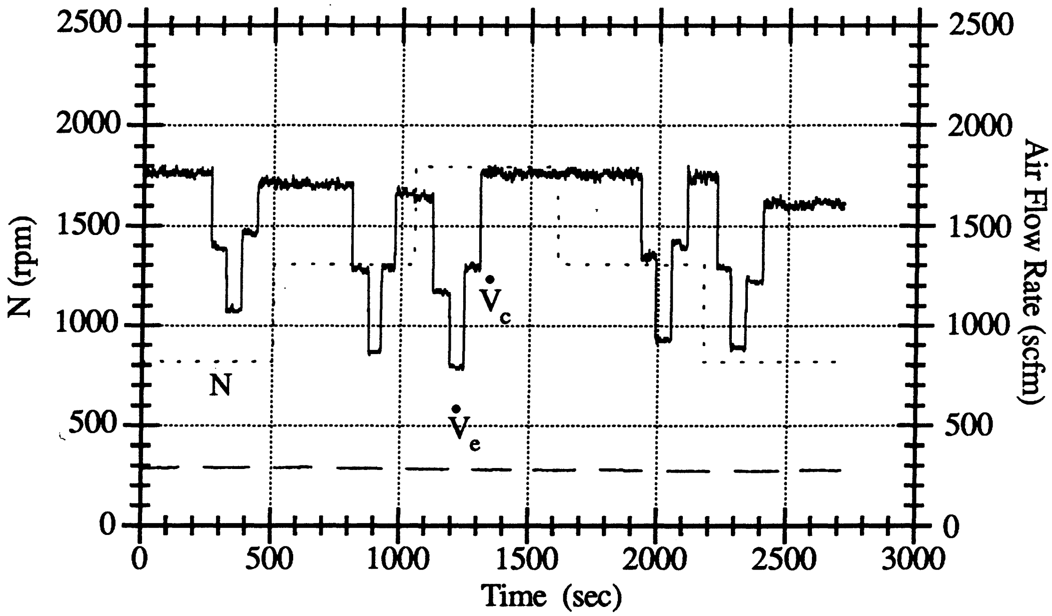

Figure 4.7. Test 4 - Compressor Speed and Condenser and Evaporator Air Flow Rates.

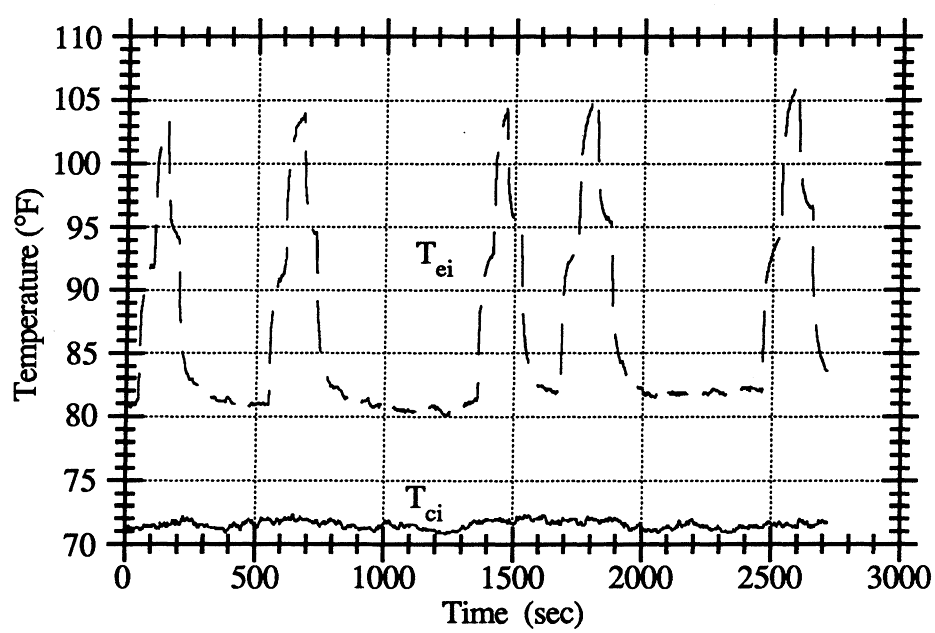

Figure 4.8. Test 4 - Evaporator and Condenser Inlet Air Temperatures.

Evaporator Inlet Air Temperature

The Component Model Developer was used to determine a suitable model form and the corresponding coefficients for each of the tests mentioned above. The first three tests investigated the effects of individual independent parameters. The last test investigated the interaction between these individual parameters in the development of a global model. Data were recorded from the test stand at one-second intervals, but a five-second interval was found to be sufficient for modeling purposes.

In the first test, the effect of evaporator inlet air temperature was studied. Figures 4.9, 4.10, and 4.11 show that there were no significant variations in the condenser pressure, power, or volumetric flow rate due to the perturbation of evaporator inlet air temperature. The model developer confirmed this finding, modeling each of these variables with a constant and finding no other parameters with significant F values (above 100).

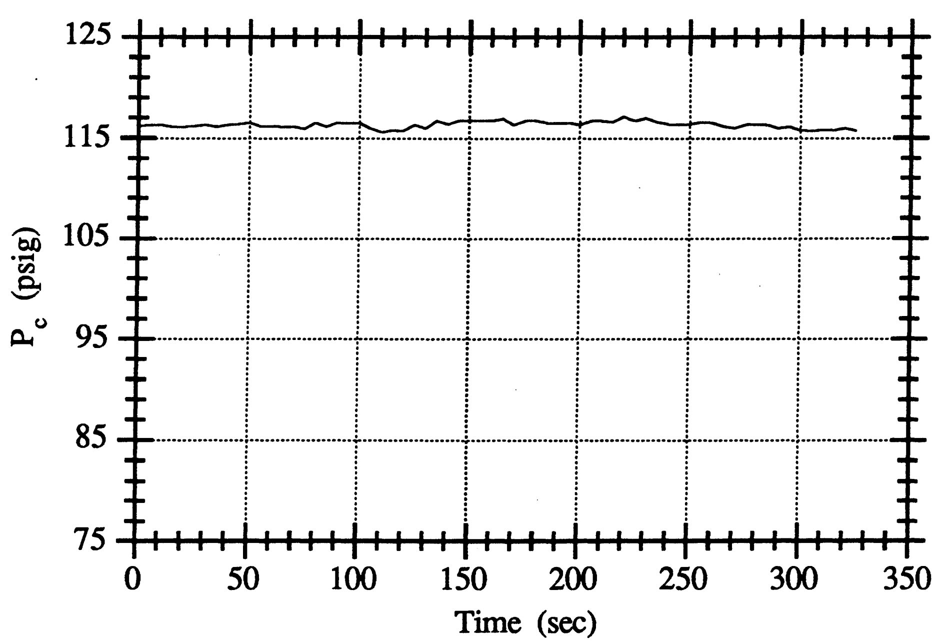

Figure 4.9. Test 1 - Condenser Pressure.

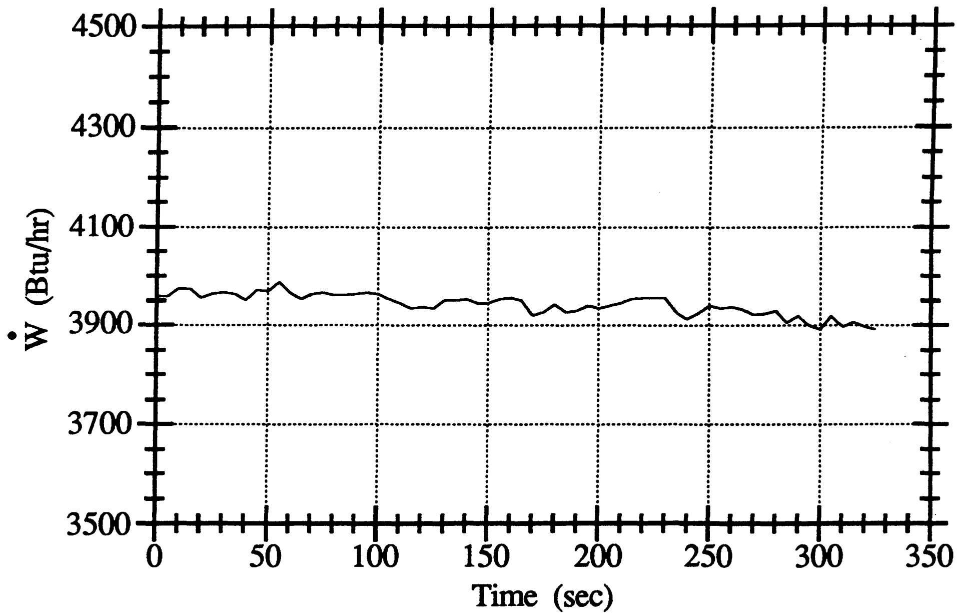

Figure 4.10. Compressor Power

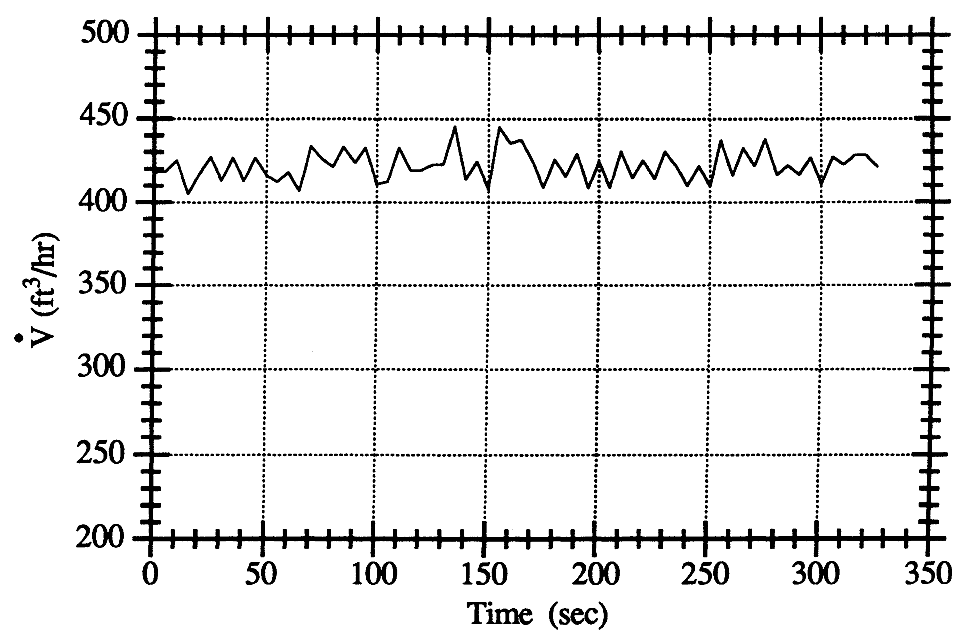

Figure 4.11. Test 1 - Compressor Inlet Volumetric Flow Rate.

Condenser Air Flow Rate

The second test investigated the effect of condenser air flow rate. The evaporator inlet air temperature and compressor speed were held constant during the course of the test. The condenser pressure model was:

$$P_c(k) = (0.6900)P_c(k-1) + (5952\ \text{psig}\cdot\text{scfm})\frac{1}{\dot{V}_c(k-1)} - (0.02572\ \frac{\text{psig}}{°\text{F}})T_{rci}(k)$$

$$+\ 37.55\ \text{psig} \qquad (4.1)$$

where $P_c(k-1)$ is the compressor inlet pressure at the previous time step, $\dot{V}_c(k-1)$ is the condenser air flow rate at the previous time step, and $T_{rci}(k)$ is the condenser inlet refrigerant temperature at the current time step. The previous condenser pressure term gives the model smooth transient response. The standard deviation of the model was 0.75 psig. Figure 4.12 shows the data and the model.

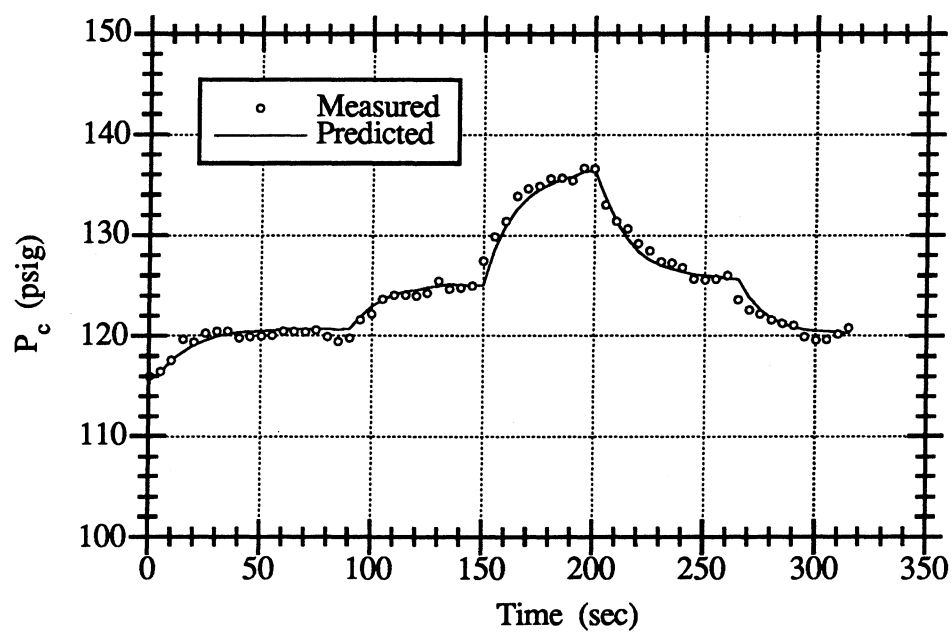

Figure 4.12. Test 2 - Condenser Pressure.

The compressor power model was:

$$\dot{W}(k) = (68.22\ \frac{\text{Btu}}{\text{hr}})R(k) - (2618\ \frac{\text{Btu}\cdot\text{lb}}{\text{hr}\cdot\text{ft}^3})\ \upsilon(k) + 7865\ \text{Btu/hr} \qquad (4.2)$$

where R(k) is the compressor discharge pressure to suction pressure ratio and $\upsilon(k)$ is the compressor inlet specific volume. Because compressor speed was held constant throughout the test, it does not appear in the model. The standard deviation of the model was 17.5 Btu/hr. Figure 4.13 shows the data and the model.

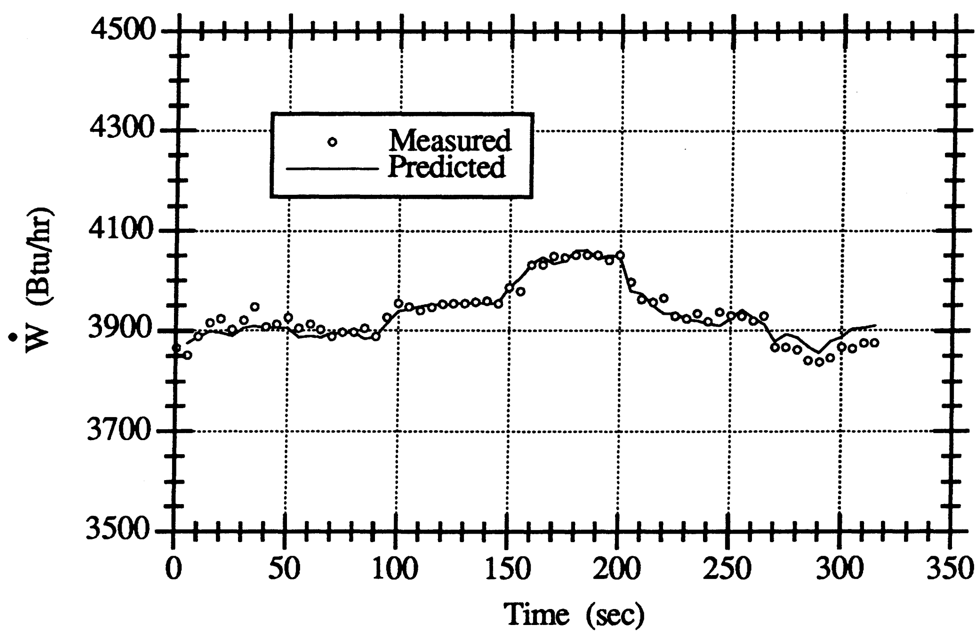

Figure 4.13. Test 2 - Compressor Power.

The condenser air flow rate did not have a significant effect on the compressor inlet volumetric flow rate as can be seen in Figure 4.14.

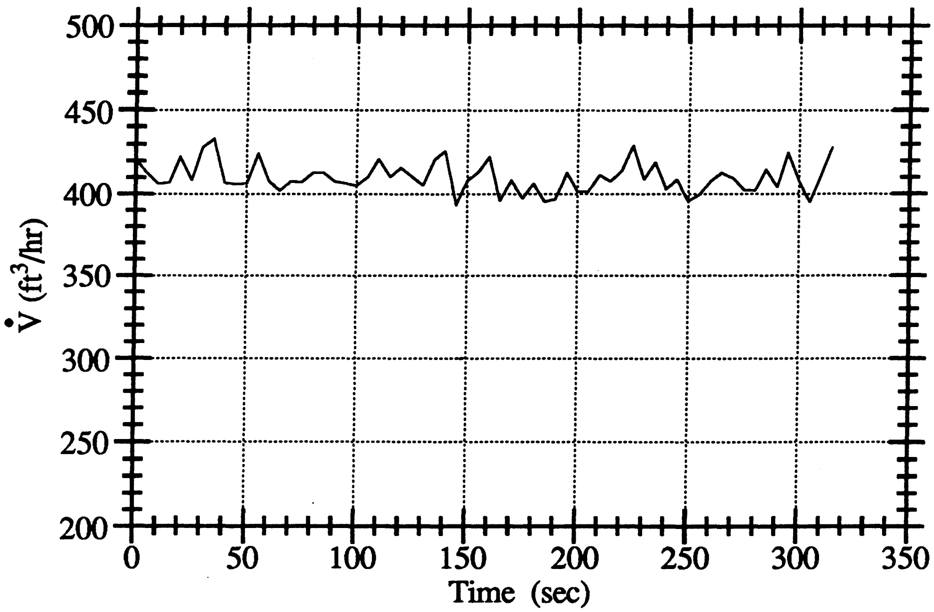

Figure 4.14. Test 2 - Compressor Inlet Volumetric Flow Rate.

Compressor Speed

The third test investigated the effect of compressor speed. For this test the condenser air flow rate and the evaporator inlet air temperature were held constant. The compressor speed had a significant effect on all of the models.

The condenser pressure model was:

$$P_c(k) = (0.6278)P_c(k\text{-}1) + (0.05441\ \frac{\text{psig}\bullet\text{hr}}{\text{lb}})\ \dot{m}(k) + (0.01091\ \frac{\text{psig}\bullet\text{hr}}{\text{lb}})\ \dot{m}(k\text{-}1)$$
$$+ (0.01594\ \frac{\text{psig}\bullet\text{hr}}{\text{lb}})\ \dot{m}(k\text{-}3) - (0.01673\ \frac{\text{psig}}{^\circ\text{F}})T_{cri}(k)$$
$$+ 22.40 \text{ psig} \tag{4.3}$$

The standard deviation of the model was 0.73 psig. Figure 4.15 shows the data and the model.

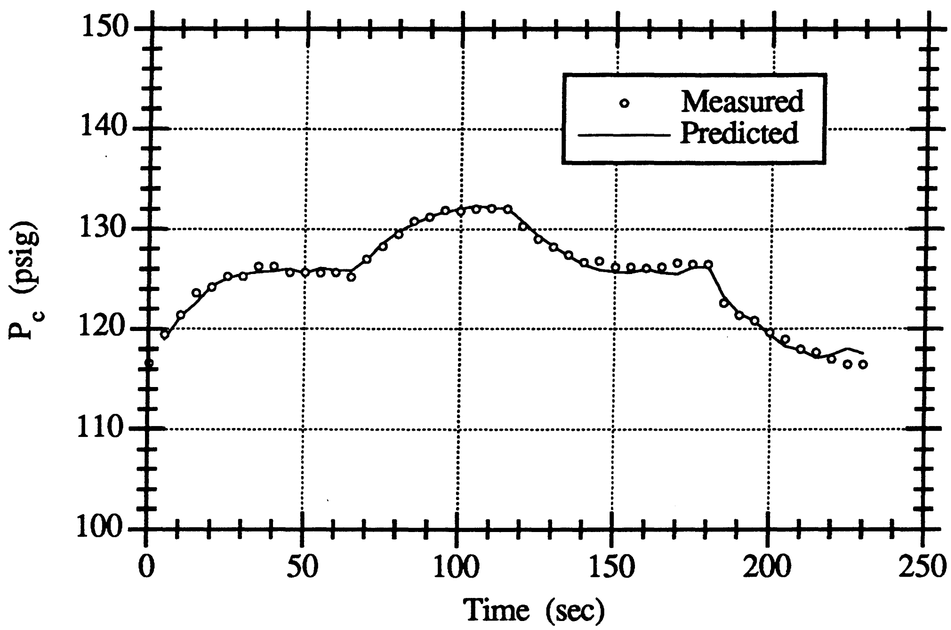

Figure 4.15. Test 3 - Condenser Pressure.

The compressor power model was:

$$\dot{W}(k) = (3.751 \frac{\text{Btu}}{\text{hr•rpm}})N(k) - (51.81 \frac{\text{Btu}}{\text{hr}})R(k) - (214.7 \frac{\text{Btu•lb}}{\text{hr•ft}^3})\,\upsilon(k) \qquad (4.4)$$

The standard deviation of the model was 37.8 Btu/hr. Figure 4.16 shows the data and the model.

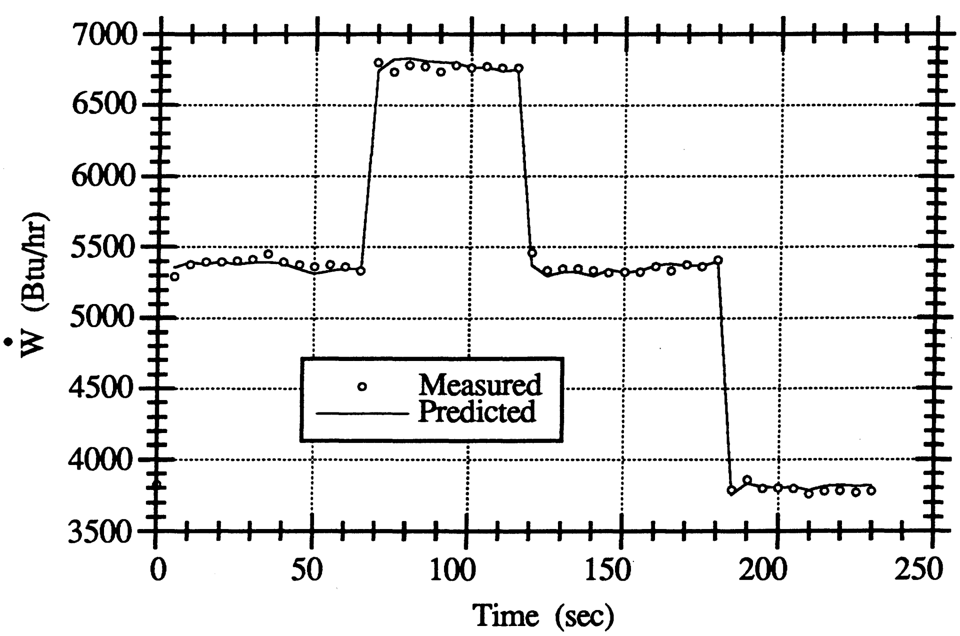

Figure 4.16. Test 3 - Compressor Power.

The compressor inlet volumetric flow rate model was:

$$\dot{V}(k) = (0.2424 \frac{ft^3}{hr \cdot rpm})N(k) - (7.527 \frac{ft^3}{hr})R(k) + (214.2 \frac{lb}{hr})\, \upsilon(k) - 207.6\ ft^3/hr \qquad (4.5)$$

The standard deviation of the model was 9.79 ft^3/hr. Figure 4.17 shows the data and the model.

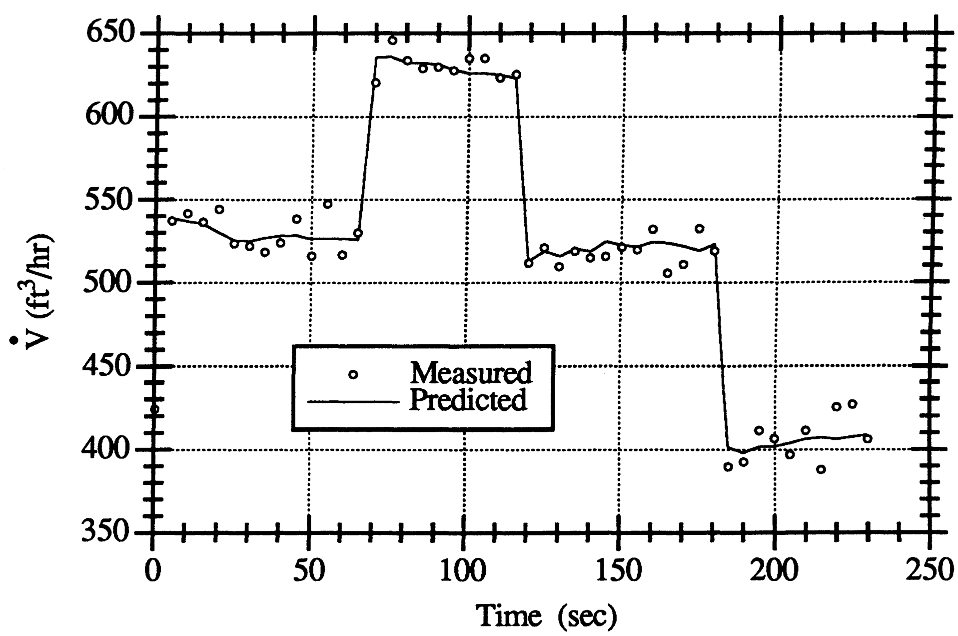

Figure 4.17. Test 3 - Compressor Inlet Volumetric Flow Rate.

Collective Models

The last test investigated the effect of compressor speed, condenser air flow rate, evaporator inlet air temperature, and the interactions between these independent parameters. It was expected that these models would have contained a collection of the terms from the various individual models developed previously. In a few instances terms that appeared in the individual models were not found to be significant in the collective models. Also in one instance a term appeared in a collective model that was not found to be significant in any of the individual models.

The collective condenser pressure model was:

$$P_c(k) = (0.8345)P_c(k\text{-}1) + (3538 \text{ psig}\bullet\text{scfm})\frac{1}{\dot{V}_c(k\text{-}1)} + (0.03300\ \frac{\text{psig}\bullet\text{hr}}{\text{lb}})\ \dot{m}(k)$$
$$+ (0.009002\ \frac{\text{psig}\bullet\text{hr}}{\text{lb}})\ \dot{m}(k\text{-}3) + (0.002967\ \frac{\text{psig}}{^\circ\text{F}})T_{rci}(k)$$
$$+ 7.372 \text{ psig} \qquad (4.6)$$

The standard deviation of the model was 1.57 psig. Figure 4.18 shows the data and the model.

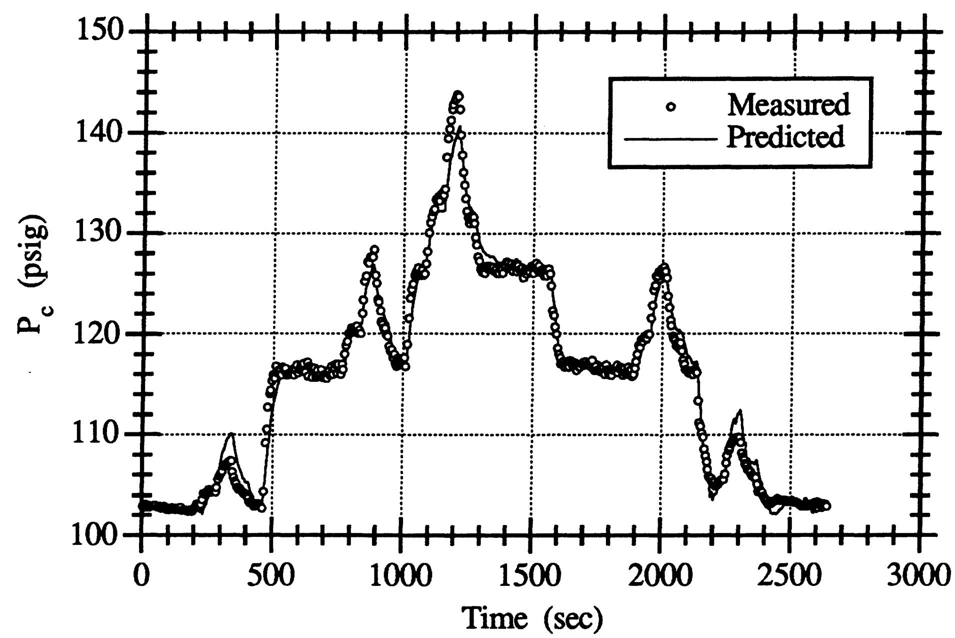

Figure 4.18. Test 4 - Condenser Pressure.

The collective compressor power model was:

$$\dot{W}(k) = (3.261\,\frac{\text{Btu}}{\text{hr•rpm}})N(k) - (0.1036\,\frac{\text{Btu}}{\text{hr•rpm}})N^2(k\text{-}1) + (4.881\,\frac{\text{Btu}}{\text{hr}})R(k) - (556.4\,\frac{\text{Btu•lb}}{\text{hr•ft}^3})\,\upsilon(k) + 650.5\ \text{Btu/hr} \qquad (4.7)$$

For this model the squared compressor speed term did not appear in the previous individual compressor speed models, but had a significant effect on the collective model. This is due to the wider range of inlet conditions experienced by the compressor. The standard deviation of the model was 28.3 Btu/hr. Figure 4.19 shows the data and the model.

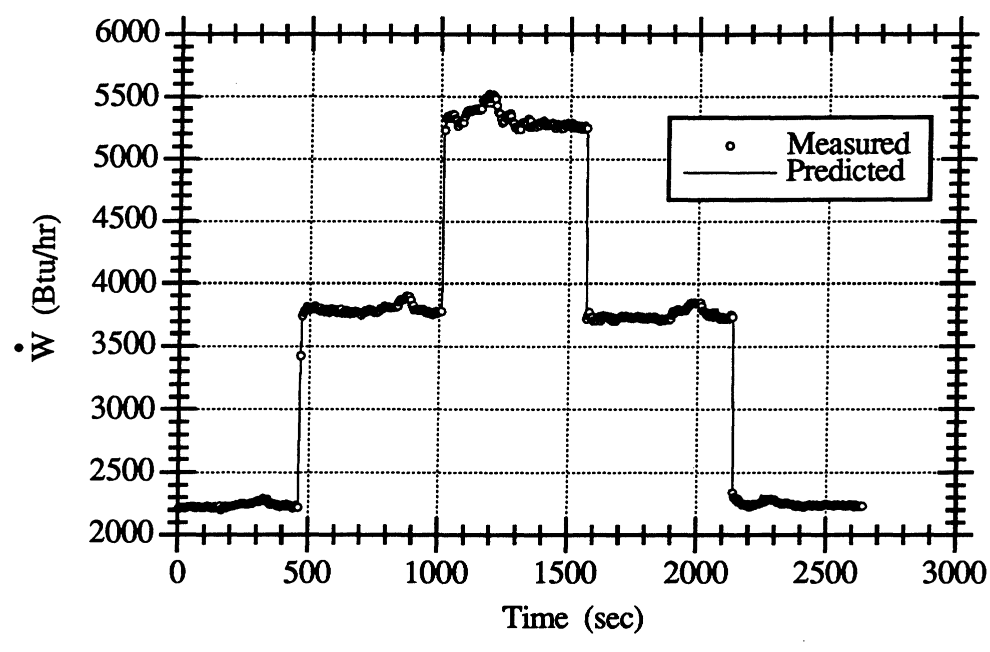

Figure 4.19. Test 4 - Compressor Power.

The collective compressor inlet volumetric flow rate model was:

$$\dot{V}(k) = (0.2926\,\frac{ft^3}{hr \cdot rpm})N(k) - (8.068\,\frac{ft^3}{hr})R(k) + (70.42\,\frac{lb}{hr})\,\upsilon(k) \qquad (4.8)$$

Since the compressor speed was found to be the only significant perturbation in the individual models, it was expected that the collective model would not differ significantly from the individual model from Test 3. Although the coefficients varied slightly from the individual model, this was found to be the case. The standard deviation of the model was 11.6 ft^3/hr. Figure 4.20 shows the data and the model.

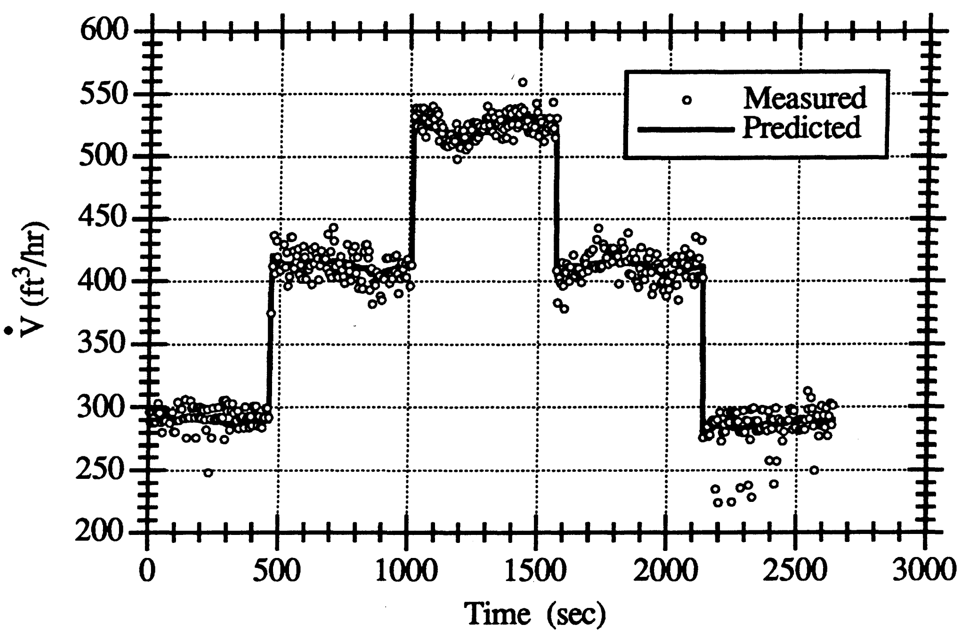

Figure 4.20. Test 4 - Compressor Inlet Volumetric Flow Rate.

CHAPTER 6

CONCLUSION

Summary

The objective of this study was to develop simple empirical models of the compressor and condenser. These models will be used in the development of advanced adaptive and optimal strategies for controlling the compressor displacement, expansion valve position, and evaporator and condenser fan speeds to improve the efficiency of mobile air conditioning systems. Because mobile air conditioning systems rarely operate in steady state conditions, the models had to respond well to sytem transients. The test facility to collect these transients was described and the models were developed using a least squares auto regressive technique.

Individual models were developed for the effects of evaporator air inlet temperature, condenser air flow rate, and compressor speed. The evaporator air inlet temperature did not significantly effect the condenser inlet pressure, compressor power, or the compressor inlet volumetric flow rate.

The condenser air flow rate had a significant effect on both the condenser pressure and the compressor power, but no significant effect on the compressor inlet volumetric flow rate. A model was developed for the condenser pressure that contained one regressive pressure term and an inverse condenser air flow term. The standard deviation was 0.75 psig. The compressor power model contained three terms and had a standard deviation of 15.5 Btu/hr.

The compressor speed affected all of the parameters. A condenser pressure model was developed with one regressive term that had a standard deviation of 0.73 psig. The compressor power was fit with a three-term model and had a standard deviation of 37.8 Btu/hr. The standard deviation for the compressor inlet volumetric flow rate model was 9.8 ft^3/hr. The model contained four terms.

Collective models were also developed for the condenser pressure, compressor power, and compressor inlet volumetric flow rate. The condenser pressure model included one regressive term and had a standard deviation of 1.57 psig. Compressor power was fit with five terms. The square of the compressor speed was a significant parameter in this model that did not appear in the previous individual models. The standard deviation was 28.3 Btu/hr. Finally, compressor inlet volumetric flow rate was fit with a three term model. The standard deviation was 11.6 ft^3/hr.

Recommendations

Several changes should be instituted in order to improve upon the current study. Currently, there is no way to control the condenser inlet air temperature and the evaporator inlet air humidity. Therfore, the effects of these variables were not investigated in this study. A humidity generation device should be installed in the evaporator loop so that the effect of passenger compartment humidity could be studied. A heater has recently been added to the condenser inlet air duct, but it does not yet have a temperature controller. Future work should also include the addition of a temperature controller on the evaporator inlet air heaters. The current setup does not allow the evaporator air flow to be changed independent of the temperature. Also, before an optimal controller could be implemented, a suitable variable displacement compressor needs to be procured and installed in the system.

Models for the evaporator outlet air temperature and evaporator outlet pressure should be developed and many other models may also be of interest to mobile air conditioning system manufacturers. The start-up period typically has the largest power consumption and the system performance could be greatly improved by optimizing the power consumption during this period. Also, a way of determining the frost accumulation on the evaporator would be of interest to an optimal controller since evaporator freeze-up should be avoided for optimal system performance.

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APPENDIX A

Data Reduction Program

TrueBasic™ Version 2.02

Modified on Macintosh IIx

```
! THIS PROGRAM WILL AVERAGE ALL THE DATA, CALCULATE REFRIGERANT
! AND AIR PROPERTIES. Version 2d (lak)

DIM DATA(17,17),AVGDATA(1,17),Temp(1,27)
DECLARE DEF entrop,sten,rhof
DECLARE DEF Hvap,Hliq,Vol,T,CPliq,CPgas
DECLARE DEF Mdvap,hSHV,sSHV,Mdliq,Mddisch
declare def rhoSHV
let view$="y"

! OPEN INPUT FILE AND OUTPUT FILES

print "Data set to be analyzed";
input data$
let data$=ucase$(data$)
OPEN #1: NAME data$ ,ACCESS INPUT, ORG TEXT

input #1: series$
if series$="s" then input #1: intr
INPUT #1: SETS

print "Save output (y)";
input save$
let save$=lcase$(save$)
if save$="y" then
  print "Name of file";
  input file$
  let file$=ucase$(file$)
  print "Type of file (Table or Normal)";
  input type$
  let type$=lcase$(type$[1:1])

  do while type$<>"n" and type$<>"t"
    print "Type T or N";
    input type$
    let type$=lcase$(type$[1:1])
  loop

  if type$="t" then
    open #3: name file$&".table",create "newold"
    ask #3: filesize fs
    if fs<>0 then
      print "Add to existing file (y)";
```

```
        input add$
        let add$=lcase$(add$)
        if add$<>"y" then
          close #3
          open #3: name file$&".table 1",create "newold"
        end if
      end if
    else
      OPEN #2: NAME file$&".norm",CREATE "NEWOLD"
      ERASE #2
    end if
  print "View output (y)";
  input view$
  let view$=lcase$(view$)
  end if

  let tme=0

  FOR XXX = 1 TO SETS STEP 1

  print " "
  if series$="s" and XXX=1 then
    INPUT #1:title$
  end if
  if series$="a" then
    INPUT #1:title$
  end if

  if series$="s" then
    if XXX=1 then
      clear
      print tab(7,5); "ANALYZING DATA SET: ";title$;"  Time = "
      let t1=time
    end if
    print tab(7,34+len(title$));tme
  else
    print  "ANALYZING DATA SET: ";title$
  end if


  if series$="s" then
    let NTEST=1
  else
    INPUT #1:NTEST
  end if

  ! REDIMENSION ARRAYS

  MAT REDIM DATA(NTEST,27)
  MAT AVGDATA = ZER(1,27)


  ! READ 1 SET OF DATA FROM INPUT FILE
```

```
if series$="s" and XXX=1 then
  INPUT #1:PAMBI                    ! AMBIENT PRESSURE, PSIA
  let PAMBI=PAMBI*.4912
end if
if series$="a" then
  INPUT #1:PAMBI                    ! AMBIENT PRESSURE, PSIA
  let PAMBI=PAMBI*.4912
end if

For i=1 to NTEST                    ! SYSTEM DATA
  mat input #1:temp
  for j=1 to 27
    let DATA(i,j)=temp(1,j)
  next j
next i

! AVERAGE ALL SYSTEM DATA

 FOR X = 1 TO 27 STEP 1
   LET SUM = 0.0
     FOR Y = 1 TO NTEST STEP 1
       LET SUM = DATA(Y,X) + SUM
     NEXT Y
   LET AVGDATA(1,X) = SUM/NTEST
 NEXT X

let TWBI=avgdata(1,27)
let avgdata(1,3)=9468.73865181*avgdata(1,3)^.8862597     ! COND SCFM
let avgdata(1,12)=262.920053609*avgdata(1,12)^.57142857   ! EVAP SCFM

! CONVERT DATA TO SI UNITS

LET PAMB  = PAMBI*6.89478                 ! KPA
LET TDB   = (AVGDATA(1,1)-32)/1.8          ! C
LET TWB   = (TWBI-32)/1.8               ! C
CALL WAMB (PAMB,TDB,TWB,WIN)                ! HUMIDITY RATIO OF AMB AIR

LET CATI  = (AVGDATA(1,1)-32)/1.8+273.15     ! K
LET CATO  = (AVGDATA(1,2)-32)/1.8+273.15     ! K

LET CAHI = 1.005*(CATI-273.15)+WIN*(2501+1.805*(CATI-273.15))  ! AIR
ENTHALPY IN, W OUT
LET CAFLO = (AVGDATA(1,3)*27.2155*.0764)             ! COND AIR MASS
FLOW, KG/HR

LET CRTI  = (AVGDATA(1,4)-32)/1.8+273.15     ! K
LET CRPI  = (AVGDATA(1,5)*6.89478)+PAMB        ! KPA
LET CRTO  = (AVGDATA(1,6)-32)/1.8+273.15     ! K
LET CRPO  = (AVGDATA(1,7)*6.89478)+PAMB        ! KPA
LET EATI  = (AVGDATA(1,8)-32)/1.8+273.15     ! K
LET EATO  = (AVGDATA(1,10)-32)/1.8+273.15    ! K
LET EARHI = (AVGDATA(1,9))               ! RH
LET EARHO = (AVGDATA(1,11))              ! RH
```

```
CALL MOISTH(PAMB,EARHO,EATO,EAHO,EAWO)                ! AIR ENTHALPY
OUT
LET EAFLO = (AVGDATA(1,12)*27.2155*.0764)             ! EVAP AIR MASS FLOW,
KG/HR

LET ERTI = (AVGDATA(1,13)-32)/1.8+273.15      ! K
LET ERPI = (AVGDATA(1,14)*6.89478)+PAMB       ! KPA
LET ERTO = (AVGDATA(1,15)-32)/1.8+273.15      ! K
LET ERPO = (AVGDATA(1,16)*6.89478)+PAMB       ! KPA
LET KRTI = (AVGDATA(1,17)-32)/1.8+273.15      ! K
LET KRPI = (AVGDATA(1,18)*6.89478)+PAMB       ! KPA
LET KRTO = (AVGDATA(1,19)-32)/1.8+273.15      ! K
LET KRPO = (AVGDATA(1,20)*6.89478)+PAMB       ! KPA
if avgdata(1,22)<10 then let avgdata(1,21)=0    ! Clutch engaged?
LET KRPM = (AVGDATA(1,21))                    ! RPM
LET KTRQ = (AVGDATA(1,22))                    ! INLB
let Msuc = Mdvap(ERPO,ERTO,avgdata(1,23))     ! lb/hr
let Mdis = Mddisch(KRPO,KRTO,avgdata(1,25))   ! lb/hr
let Mliq = Mdliq(CRTO,avgdata(1,24))          ! lb/hr
LET RFLOW = (Mliq*.4536)                      ! KG/HR

! CALCULATE ALL REFRIGERANT AND REMAINING AIR PROPERTIES

CALL MOISTH(PAMB,CARHI,CATI,CAHI,CAWI)
LET CAHO = 1.005*(CATO-273.15) + CAWI*(2501+1.805*(CATO-273.15))
LET CRHI = hSHV(CRTI-T(CRPI),T(CRPI))
LET CRHO = Hliq(CRTO)
LET CRFLOW = CAFLO*(CAHO-CAHI)/(CRHI-CRHO)
CALL MOISTH(PAMB,EARHI,EATI,EAHI,EAWI)
let dwater=EAFLO*(EAWI-EAWO)
LET ERHO = hSHV(ERTO-T(ERPO),T(ERPO))
let ERHI = CRHO
let KRHI = hSHV(KRTI-T(KRPI),T(KRPI))
let KRHO = hSHV(KRTO-T(KRPO),T(KRPO))
let KRvI = 1/((rhoSHV(KRTI-T(KRPI),T(KRPI)))*.062428)
let KRvO = 1/((rhoSHV(KRTO-T(KRPO),T(KRPO)))*.062428)

!Calculate capacity, COP, etc.

let Power=AVGDATA(1,21)*AVGDATA(1,22)/24.769
if power=0 then let power=0.01
let Capacity=(ERHO-ERHI)*0.42992*Mliq
let Qcomp=Power-(KRHO-KRHI)*0.42992*Mliq
let Qcond=(CRHI-CRHO)*0.42992*Mliq
let Qsuct=(KRHI-ERHO)*0.42992*Mliq
let Qdisc=(KRHO-CRHI)*0.42992*Mliq
let Esuper=ERTO-T(ERPO)
let Csub=T(CRPO)-CRTO

! PRINT OUTPUT (ALL PROPERTIES AND MEASUREMENTS)

LET FORM$ = "################### ######.# <######"
if view$="y" then
  print " "
```

```
PRINT "    DATA SET ";title$;
if series$="s" then
  print " Time =";tme
else
  print
end if
PRINT " "
PRINT using form$: "COND AIR T IN   =",AVGDATA(1,1),"°F"
PRINT using form$: "COND AIR T OUT  =",AVGDATA(1,2),"°F"
PRINT using form$: "COND AIR CFM    =",AVGDATA(1,3),"SCFM"
PRINT using form$: "COND REF T IN   =",AVGDATA(1,4),"°F"
PRINT using form$: "COND REF Pg IN  =",AVGDATA(1,5),"psig"
PRINT using form$: "COND REF T OUT  =",AVGDATA(1,6),"°F"
PRINT using form$: "COND REF Pg OUT =",AVGDATA(1,7),"psig"
print using form$: "Cond Ref dp     =",AVGDATA(1,5)-AVGDATA(1,7),"psid"
PRINT using form$: "EVAP AIR T IN   =",AVGDATA(1,8),"°F"
PRINT using form$: "EVAP AIR RH IN  =",AVGDATA(1,9),"%"
PRINT using form$: "EVAP AIR T OUT  =",AVGDATA(1,10),"°F"
PRINT using form$: "EVAP AIR RH OUT =",AVGDATA(1,11),"%"
PRINT using form$: "EVAP AIR FLOW   =",AVGDATA(1,12),"SCFM"
PRINT using form$: "EVAP REF T IN   =",AVGDATA(1,13),"°F"
PRINT using form$: "EVAP REF Pg IN  =",AVGDATA(1,14),"psig"
PRINT using form$: "EVAP REF T OUT  =",AVGDATA(1,15),"°F"
PRINT using form$: "EVAP REF Pg OUT =",AVGDATA(1,16),"psig"
print using form$: "Evap Ref dp     =",AVGDATA(1,14)-AVGDATA(1,16),"psid"
PRINT using form$: "COMP REF T  IN  =",AVGDATA(1,17),"°F"
PRINT using form$: "COMP REF Pg IN  =",AVGDATA(1,18),"psig"
PRINT using form$: "COMP REF T OUT  =",AVGDATA(1,19),"°F"
PRINT using form$: "COMP REF Pg OUT =",AVGDATA(1,20),"psig"
PRINT using form$: "COMP SPEED      =",AVGDATA(1,21),"RPM"
PRINT using form$: "COMP TORQUE     =",AVGDATA(1,22),"in•lb"
PRINT using form$: "AMB AIR PRESS   =",PAMB/6.89478,"psia"
PRINT using form$: "AMB AIR T DB    =",TDB*1.8 + 32,"°F"
PRINT using form$: "AMB AIR T WB    =",TWB*1.8 + 32,"°F"
PRINT using form$: "COND AIR DELT H =",(CAHO-CAHI)*0.42992,"Btu/lb"
PRINT using form$: "COND AIR MFLOW  =",CAFLO/.4536,"lb/hr"
PRINT using form$: "COND REF H IN   =",CRHI*0.42992,"Btu/lb"
PRINT using form$: "COND REF H OUT  =",CRHO*0.42992,"Btu/lb"
PRINT using form$: "EVAP AIR DELT H =",(EAHI-EAHO)*0.42992,"Btu/lb"
PRINT using form$: "EVAP AIR MFLOW  =",EAFLO/.4536,"lb/hr"
PRINT using form$: "EVAP REF H IN   =",ERHI*0.42992,"Btu/lb"
PRINT using form$: "EVAP REF H OUT  =",ERHO*0.42992,"Btu/lb"
PRINT using form$: "COMP REF H IN   =",KRHI*0.42992,"Btu/lb"
PRINT using form$: "COMP REF H OUT  =",KRHO*0.42992,"Btu/lb"
PRINT using form$: "COMP REF v IN   =",KRvI,"ft^3/lb"
PRINT using form$: "COMP REF v OUT  =",KRvO,"ft^3/lb"
PRINT " "
PRINT using form$: "SUCT FLOW RATE  =",Msuc,"lb/hr"
print using form$: "Disch. Flow Rate =",Mdis,"lb/hr"
print using form$: "Liq. Flow Rate  =",Mliq,"lb/hr"
PRINT using form$: "CALCULATED FLOW =",CRFLOW/.4536,"lb/hr"
PRINT " "
print using form$: "COP             =",Capacity/Power
print using form$: "Power           =",Power,"Btu/hr"
```

```
  print using form$:  "Capacity   =",Capacity,"Btu/hr"
  print using form$:  "Qcomp      =",Qcomp,"Btu/hr"
  print using form$:  "Qcond      =",Qcond,"Btu/hr"
  print using form$:  "Qsuction   =",Qsuct,"Btu/hr"
  print using form$:  "Qdischarge =",Qdisc,"Btu/hr"
  print  " "
  print using form$:  "Evap. Superheat  =",Esuper*1.8,"°F"
  print using form$:  "Cond. Subcooling =",Csub*1.8,"°F"
  print  " "
  print using form$:  "Condensation Rate =",dwater/.4536,"lb/hr"
  print  " "
  print  " "

end if

!Save output

if save$="y" then

 if type$="n" then
  print #2: " "
  PRINT #2: "    DATA SET ";title$;
  if series$="s" then
    print #2: "  Time =";tme
  else
    print #2:
  end if
  PRINT #2: " "
  PRINT #2: " "
  PRINT #2, using form$: "COND AIR T IN   =",AVGDATA(1,1),"°F"
  PRINT #2, using form$: "COND AIR T OUT  =",AVGDATA(1,2),"°F"
  PRINT #2, using form$: "COND AIR CFM    =",AVGDATA(1,3),"SCFM"
  PRINT #2, using form$: "COND REF T IN   =",AVGDATA(1,4),"°F"
  PRINT #2, using form$: "COND REF Pg IN  =",AVGDATA(1,5),"psig"
  PRINT #2, using form$: "COND REF T OUT  =",AVGDATA(1,6),"°F"
  PRINT #2, using form$: "COND REF Pg OUT =",AVGDATA(1,7),"psig"
  print #2, using form$: "Cond Ref dp     =",AVGDATA(1,5)-AVGDATA(1,7),"psid"
  PRINT #2, using form$: "EVAP AIR T IN   =",AVGDATA(1,8),"°F"
  PRINT #2, using form$: "EVAP AIR RH IN  =",AVGDATA(1,9),"%"
  PRINT #2, using form$: "EVAP AIR T OUT  =",AVGDATA(1,10),"°F"
  PRINT #2, using form$: "EVAP AIR RH OUT =",AVGDATA(1,11),"%"
  PRINT #2, using form$: "EVAP AIR FLOW   =",AVGDATA(1,12),"SCFM"
  PRINT #2, using form$: "EVAP REF T IN   =",AVGDATA(1,13),"°F"
  PRINT #2, using form$: "EVAP REF Pg IN  =",AVGDATA(1,14),"psig"
  PRINT #2, using form$: "EVAP REF T OUT  =",AVGDATA(1,15),"°F"
  PRINT #2, using form$: "EVAP REF Pg OUT =",AVGDATA(1,16),"psig"
  print #2, using form$: "Evap Ref dp     =",AVGDATA(1,14)-AVGDATA(1,16),"psid"
  PRINT #2, using form$: "COMP REF T  IN  =",AVGDATA(1,17),"°F"
  PRINT #2, using form$: "COMP REF Pg IN  =",AVGDATA(1,18),"psig"
  PRINT #2, using form$: "COMP REF T OUT  =",AVGDATA(1,19),"°F"
  PRINT #2, using form$: "COMP REF Pg OUT =",AVGDATA(1,20),"psig"
  PRINT #2, using form$: "COMP SPEED      =",AVGDATA(1,21),"RPM"
  PRINT #2, using form$: "COMP TORQUE     =",AVGDATA(1,22),"in•lb"
  PRINT #2, using form$: "AMB AIR PRESS   =",PAMB/6.89478   ,"psia"
```

```
PRINT #2, using form$: "AMB AIR T DB    =",TDB*1.8 + 32,"°F"
PRINT #2, using form$: "AMB AIR T WB    =",TWB*1.8 + 32,"°F"
PRINT #2, using form$: "COND AIR DELT H =",(CAHO-CAHI)*0.42992,"Btu/lb"
PRINT #2, using form$: "COND AIR MFLOW  =",CAFLO/.4536,"lb/hr"
PRINT #2, using form$: "COND REF H IN   =",CRHI*0.42992,"Btu/lb"
PRINT #2, using form$: "COND REF H OUT  =",CRHO*0.42992,"Btu/lb"
PRINT #2, using form$: "EVAP AIR DELT H =",(EAHI-EAHO)*0.42992,"Btu/lb"
PRINT #2, using form$: "EVAP AIR MFLOW  =",EAFLO/.4536,"lb/hr"
PRINT #2, using form$: "EVAP REF H IN   =",ERHI*0.42992,"Btu/lb"
PRINT #2, using form$: "EVAP REF H OUT  =",ERHO*0.42992,"Btu/lb"
PRINT #2, using form$: "COMP REF H IN   =",KRHI*0.42992,"Btu/lb"
PRINT #2, using form$: "COMP REF H OUT  =",KRHO*0.42992,"Btu/lb"
PRINT #2, using form$: "COMP REF v IN   =",KRvI,"ft^3/lb"
PRINT #2, using form$: "COMP REF v OUT  =",KRvO,"ft^3/lb"
PRINT #2, using form$: " "
PRINT #2, using form$: "SUCT FLOW RATE  =",Msuc,"lb/hr"
print #2, using form$: "Disch. Flow Rate =",Mdis,"lb/hr"
print #2, using form$: "Liq. Flow Rate  =",Mliq,"lb/hr"
PRINT #2, using form$: "CALCULATED FLOW =",CRFLOW/.4536,"lb/hr"
PRINT #2: " "
PRINT #2: " "
print #2, using form$: "COP        =",Capacity/Power
print #2, using form$: "Power      =",Power,"Btu/hr"
print #2, using form$: "Capacity   =",Capacity,"Btu/hr"
print #2, using form$: "Qcomp      =",Qcomp,"Btu/hr"
print #2, using form$: "Qcond      =",Qcond,"Btu/hr"
print #2, using form$: "Qsuction   =",Qsuct,"Btu/hr"
print #2, using form$: "Qdischarge =",Qdisc,"Btu/hr"
print #2: " "
print #2, using form$: "Evap. Superheat  =",Esuper*1.8,"°F"
print #2, using form$: "Cond. Subcooling =",Csub*1.8,"°F"
print #2: " "
print #2, using form$: "Condensation Rate =",dwater/.4536,"lb/hr"
print #2: " "
print #2: " "
else
  ask #3: filesize fs
  set #3: margin 600
  reset #3: end
  if 1=1 and fs=0 then
    print #3:sets
    if series$="s" then print #3:"Time  (sec),";
    print #3:"Con a Tin,Con a To,Con a flow,Con r Tin,Con r Pin,Con r To,Con r Po,Con r
ΔP,";
    print #3:"Evp a Tin,Evp a RHi,Evp a To,Evp a RHo,Evp a flow,Evp r Tin,Evp r
Pin,Evp r To,Evp r Po,";
    print #3:"Evp r ΔP,Com r Tin,Com r Pin,Com r To,Com r Po,Com Speed,Com
Torque,Amb air P,";
    print #3:"Amb air Tdb,Amb air Twb,Con a Δh,Con a Mdot,Con r hin,Con r ho,Evp a
Δh,Evp a Mdot,";
    print #3:"Evp r hin,Evp r ho,Com r hin,Com r ho,Com r vin,Com r vo,Suct Flow,Disc
Flow,Liq Flow,Calc Flow,COP,";
```

```
print
#3:"Power,Capacity,Qcomp,Qcond,Qsuction,Qdischarge,Superheat,Subcooling,Condensation
"
    end if
    if series$="s" then print #3:tme;",";
    for i=1 to 7
       print #3:round(avgdata(1,i),2);",";
    next i
    print #3:round(avgdata(1,5)-avgdata(1,7),2);",";
    for i=8 to 16
       print #3:round(avgdata(1,i),2);",";
    next i
    print #3:round(avgdata(1,14)-avgdata(1,16),2);",";
    for i=17 to 22
       print #3:round(avgdata(1,i),2);",";
    next i
    print #3:round(PAMB/6.89478,2);",";round(TDB*1.8 + 32,2);",";round(TWB*1.8 +
32,2);",";
    print #3:round((CAHO-
CAHI)*0.42992,2);",";round(CAFLO/.4536,2);",";round(CRHI*0.42992,2);",";
    print #3:round(CRHO*0.42992,2);",";round((EAHI-
EAHO)*0.42992,2);",";round(EAFLO/.4536,2);",";
    print
#3:round(ERHI*0.42992,2);",";round(ERHO*0.42992,2);",";round(KRHI*0.42992,2);",";
    print #3:round(KRHO*0.42992,2);",";round(KRvI,2);",";round(KRvO,2);",";
    print #3:round(Msuc,2);",";round(Mdis,2);",";round(Mliq,2);",";
    print #3:round(CRFLOW/.4536,2);",";round(Capacity/Power,2);",";round(Power,2);",";
    print
#3:round(Capacity,2);",";round(Qcomp,2);",";round(Qcond,2);",";round(Qsuct,2);",";
    print
#3:round(Qdisc,2);",";round(Esuper*1.8,2);",";round(Csub*1.8,2);",";round(dwater/.4536,3
)
  end if
end if
let tme=tme+intr

if XXX=1 then
  let t2=time
  print tab(5,5); "Minutes remaining: "
end if
if XXX=1 or XXX/10=int(XXX/10) then
  print tab(5,24); "      "
  print tab(5,24);round((sets-XXX)*(t2-t1)/60,2)
end if

NEXT XXX

! CLOSE ALL FILES

CLOSE #1
CLOSE #2
CLOSE #3

END
```

```
sub wamb (PAMB,TDB,TWB,WIN)

! Calculate W for air given Pressure, Twb, and Tdb.
! Temperatures in C.  Pressure in kPa.

let c1  = -5.6745359e3
let c2  = -5.1523057e-1
let c3  = -9.6778430e-3
let c4  = 6.2215701e-7
let c5  = 2.0747825e-9
let c6  = -9.484024e-13
let c7  = 4.1635019
let c8  = -5.8002206e3
let c9  = -5.5162560
let c10 = -4.8640239e-2
let c11 = 4.1764768e-5
let c12 = -1.4452093e-8
let c13 = 6.5459673

let twb = twb + 273.15

if twb < 273.15 then
  let pws = exp(c1/twb + c2 + c3*twb + c4*twb^2 + c5*twb^3 + c6*twb^4 + c7*log(twb))
else
  let pws = exp(c8/twb + c9 + c10*twb + c11*twb^2 + c12*twb^3 + c13*log(twb))
end if

let ws  = .62198*pws/(pamb-pws)
let twb = twb - 273.15

let win = ((2501-2.381*twb)*ws-(tdb-twb))/(2501+(1.805*tdb)-(4.186*twb))

end sub

sub moisth(p,phi,t,h,w)
!
! MOIST AIR ENTHALPY GIVEN RELATIVE HUMIDITY AND TEMPERATURE.
! W IS HUMIDITY RATIO AT SPECIFIED RH AND TEMPERATURE
!
! PRESSURE IN kPa
! TEMPERATURE IN K
! ENTHALPY IN KJ/KG

let c1  = -5.6745359e3
let c2  = -5.1523057e-1
let c3  = -9.6778430e-3
let c4  = 6.2215701e-7
let c5  = 2.0747825e-9
let c6  = -9.484024e-13
let c7  = 4.1635019
let c8  = -5.8002206e3
let c9  = -5.5162560
let c10 = -4.8640239e-2
```

```
let c11 = 4.1764768e-5
let c12 = -1.4452093e-8
let c13 = 6.5459673

if t < 273.15 then
  let pws = exp(c1/t + c2 + c3*t + c4*t^2 + c5*t^3 + c6*t^4 + c7*log(t))
else
  let pws = exp(c8/t + c9 + c10*t + c11*t^2 + c12*t^3 + c13*log(t))
end if

let pw = phi/100.0 * pws
let w  = 0.62198*pw/(p - pw)
let h  = 1.005*(t-273.15) + w*(2501 + 1.805*(t-273.15))

end sub


Def Densliq(T)
  !TEMPERATURE (K), DENSITY (KG/M^3) DATA FOR R12

  !COEFFICIENTS...T=220-370 °K
  let C1=766.953
  let C2=-787.526
  let C3=5636.57
  let C4=-6671.89
  let C5=3202.81

  LET X = (1 - T/384.95)^(1/3)
  let Densliq = C1 + C2*X + C3*X^2 + C4*X^3 + C5*X^4
end Def

Def Hliq(T)
  !TEMPERATURE (K), LIQ. ENTHALPY (KJ/KG) DATA FOR R12

  !COEFFICIENTS...T= 220-370 °K
  let C1=624.164
  let C2=-5.53819
  let C3=.034685
  let C4=-8.42386e-5
  let C5=7.83359e-8

  let Hliq = C1 + C2*T + C3*T^2 + C4*T^3 + C5*T^4

end Def

Def Hvap(T)
  !TEMPERATURE (K), VAP. ENTHALPY (KJ/KG) DATA FOR R12
  If T>295 then
    !COEFFICIENTS...T= 270-370 °K
    let C1=-2156.97
    let C2=35.0819
    let C3=-.173056
    let C4=3.85794e-4
    let C5=-3.243e-7
```

```
    let Hvap = C1 + C2*T + C3*T^2 + C4*T^3 + C5*T^4
   Else
    !COEFFICIENTS...T=220-320 °K
    let C1=384.619
    let C2=1.53814
    let C3=-7.39091e-3
    let C4=2.2906e-5
    let C5=-2.68065e-8

    let hvap = C1 + C2*T + C3*T^2 + C4*T^3 + C5*T^4
   end if
  end Def

  Def P(T)

   !TEMPERATURE (K), PRESSURE (KPA) DATA FOR R12

   !COEFFICIENTS...T=220-370 °K
   let C1=-34.5426
   let C2=.371808
   let C3=-1.34106e-3
   let C4=2.33422e-6
   let C5=-1.58017e-9

   let lnp = C1 + C2*T + C3*T^2 + C4*T^3 + C5*T^4
   let P=exp(lnp)
  end Def

  Def Sliq(T)
   !TEMPERATURE (K), LIQ. ENTROPY (KJ/KG) DATA FOR R12
   if T>305 then
    !COEFFICIENTS...T=290-370 °K
    let C1=12.7429
    let C2=-.118725
    let C3=5.88984e-4
    let C4=-1.26023e-6
    let C5=1.00816e-9

    let Sliq = C1 + C2*T + C3*T^2 + C4*T^3 + C5*T^4
   else
    !COEFFICIENTS...T=220-320 °K
    let C1=2.66171
    let C2=9.06035e-3
    let C3=-1.75857e-5
    let C4=1.76573e-8

    let Sliq = C1 + C2*T + C3*T^2 + C4*T^3
   end if
  end Def

  Def Svap(T)
   !TEMPERATURE (K), VAP. ENTROPY (KJ/KG-K) DATA FOR R12
   if T<305 then
```

```
   !COEFFICIENTS...T=220-320 °K
   let C1=6.32369
   let C2=-1.49816e-2
   let C3=4.77448e-5
   let C4=-5.15929e-8

   let Svap = C1 + C2*T + C3*T^2 + C4*T^3
  else
   !COEFFICIENTS...T=290-370 °K
   let C1=-7.36119
   let C2=.15774
   let C3=-7.68432e-4
   let C4=1.65969e-6
   let C5=-1.34324e-9

   let Svap = C1 + C2*T + C3*T^2 + C4*T^3 + C5*T^4
  end if
end Def

Def T(P)
  !TEMPERATURE (K), PRESSURE (KPA) DATA FOR R12

  !COEFFICIENTS...P= 33.11-3154.1 kPa
  let C1=149.276
  let C2=26.1907
  let C3=-3.14803
  let C4=.409312

  let T = C1 + C2*log(P) + C3*(log(P))^2 + C4*(log(P))^3

End def

Def Vol(T)
  !TEMPERATURE (K), SPECIFIC VOLUME (M^3/KG) DATA FOR R12

  !COEFFICIENTS...T=220-370 °K
  let C1=13.7356
  let C2=7.65959
  let C3=-35.6923
  let C4=-32.4574
  let C5=8.36175

  LET TRATIO = T/384.95
  let lnv = C1 + C2/TRATIO + C3*TRATIO + C4*(1 - TRATIO)^(1.5) + C5*TRATIO^3
  let Vol=exp(lnv)
end Def

Def CPliq(T)
  !Liquid specific heat  T=170-370 °K

  let m0 =      -17.462567872
  let m1 =      0.42877339342
  let m2 =      -0.0041129649668
  let m3 =      2.0551213662e-05
```

```
 let m4 =        -5.6012650636e-08
 let m5 =        7.8277553688e-11
 let m6 =        -4.3101928075e-14

 let CPliq = m0 + m1*T + m2*T^2 + m3*T^3 + m4*T^4 + m5*T^5 + m6*T^6

end Def

Def Cvsup(T)
 !R12 CV superheat, T=270-360 °K  (EES)

 let m0 = 0.42314505035
 let m1 = 0.00024076022885
 let m2 = 6.8181391918e-07

 let CVsup = m0 + m1*T + m2*T^2

end Def

Def CPsup(T)
 !R12 CP superheat, T=270-360 °K  (EES)

 let m0 = 0.59530786818
 let m1 = -0.00029628042019
 let m2 = 1.4015038808e-06
 let CPsup = m0 + m1*T + m2*T^2

end Def

def rhoSHV(Tsuper,Tsat)
 dim c(16),f(1,16),temp(1),x1(1),x2(1)

 !coefficients...Tsat=224-306 °K
 let C(1)  = -390.06
 let C(2)  = 5.93507
 let C(3)  = -7.85603e-2
 let C(4)  = 4.81705e-4
 let C(5)  = 5.28265
 let C(6)  = -.07476
 let C(7)  = 9.68992e-4
 let C(8)  = -5.89571e-6
 let C(9)  = -2.43388e-2
 let C(10) = 3.16394e-4
 let C(11) = -3.99123e-6
 let C(12) = 2.40444e-8
 let C(13) = 3.83185e-5
 let C(14) = -4.51724e-7
 let C(15) = 5.50131e-9
 let C(16) = -3.27168e-11

let x1(1)=Tsuper
let x2(1)=Tsat

DEF f1(x,z)=1
```

```
DEF f2(x,z)=X
DEF f3(x,z)=X^2
DEF f4(x,z)=X^3
DEF f5(x,z)=z
DEF f6(x,z)=Z*X
DEF f7(x,z)=Z*X^2
DEF f8(x,z)=Z*X^3
DEF f9(x,z)=Z^2
DEF f10(x,z)=(Z^2)*X
DEF f11(x,z)=(Z^2)*X^2
DEF f12(x,z)=(Z^2)*X^3
DEF f13(x,z)=Z^3
DEF f14(x,z)=(Z^3)*X
DEF f15(x,z)=(Z^3)*X^2
DEF f16(x,z)=(Z^3)*X^3

let i=1

LET f(i,1)=f1(X1(i),X2(i))
LET f(i,2)=f2(X1(i),X2(i))
LET f(i,3)=f3(X1(i),X2(i))
LET f(i,4)=f4(X1(i),X2(i))
LET f(i,5)=f5(X1(i),X2(i))
LET f(i,6)=f6(X1(i),X2(i))
LET f(i,7)=f7(X1(i),X2(i))
LET f(i,8)=f8(X1(i),X2(i))
LET f(i,9)=f9(X1(i),X2(i))
LET f(i,10)=f10(X1(i),X2(i))
LET f(i,11)=f11(X1(i),X2(i))
LET f(i,12)=f12(X1(i),X2(i))
LET f(i,13)=f13(X1(i),X2(i))
LET f(i,14)=f14(X1(i),X2(i))
LET f(i,15)=f15(X1(i),X2(i))
LET f(i,16)=f16(X1(i),X2(i))

MAT temp=f*C
let rhoSHV=temp(1)

END DEF

def hSHV(Tsuper,Tsat)
 dim c(16),f(1,16),temp(1),x1(1),x2(1)

 !coefficients...Tsat=224-306 °K
 let C(1)  = 679.864
 let C(2)  = -95.046
 let C(3)  = 5.27068
 let C(4)  = -5.88012e-2
 let C(5)  = -2.3407
 let C(6)  = 1.0926
 let C(7)  = -6.03105e-2
 let C(8)  = 6.72955e-4
 let C(9)  = 1.10903e-2
 let C(10) = -4.13218e-3
```

```
  let C(11) = 2.28069e-4
  let C(12) = -2.54482e-6
  let C(13) = -1.45752e-5
  let C(14) = 5.17965e-6
  let C(15) = -2.85292e-7
  let C(16) = 3.18285e-9

  let x1(1)=Tsuper
  let x2(1)=Tsat

  DEF f1(x,z)=1
  DEF f2(x,z)=X
  DEF f3(x,z)=X^2
  DEF f4(x,z)=X^3
  DEF f5(x,z)=z
  DEF f6(x,z)=Z*X
  DEF f7(x,z)=Z*X^2
  DEF f8(x,z)=Z*X^3
  DEF f9(x,z)=Z^2
  DEF f10(x,z)=(Z^2)*X
  DEF f11(x,z)=(Z^2)*X^2
  DEF f12(x,z)=(Z^2)*X^3
  DEF f13(x,z)=Z^3
  DEF f14(x,z)=(Z^3)*X
  DEF f15(x,z)=(Z^3)*X^2
  DEF f16(x,z)=(Z^3)*X^3

  let i=1

  LET f(i,1)=f1(X1(i),X2(i))
  LET f(i,2)=f2(X1(i),X2(i))
  LET f(i,3)=f3(X1(i),X2(i))
  LET f(i,4)=f4(X1(i),X2(i))
  LET f(i,5)=f5(X1(i),X2(i))
  LET f(i,6)=f6(X1(i),X2(i))
  LET f(i,7)=f7(X1(i),X2(i))
  LET f(i,8)=f8(X1(i),X2(i))
  LET f(i,9)=f9(X1(i),X2(i))
  LET f(i,10)=f10(X1(i),X2(i))
  LET f(i,11)=f11(X1(i),X2(i))
  LET f(i,12)=f12(X1(i),X2(i))
  LET f(i,13)=f13(X1(i),X2(i))
  LET f(i,14)=f14(X1(i),X2(i))
  LET f(i,15)=f15(X1(i),X2(i))
  LET f(i,16)=f16(X1(i),X2(i))

 MAT temp=f*C
 let hSHV=temp(1)

END DEF

def sSHV(T,Tsat)

  !T=223-430 °K
```

```
dim c(25),f(1,25),yc(1),x1(1),x2(1)

let C(1) = -2039.09
let C(2) = 27.8276
let C(3) = -.14134
let C(4) = 3.17452e-4
let C(5) = -2.66073e-7
let C(6) = 85506.6
let C(7) = -1161.8
let C(8) = 5.88891
let C(9) = -1.31998e-2
let C(10) = 1.10412e-5
let C(11) = -1.05362e+6
let C(12) = 14283.9
let C(13) = -72.2359
let C(14) = .161532
let C(15) = -1.3479e-4
let C(16) = 4.94368e+6
let C(17) = -66819.
let C(18) = 336.841
let C(19) = -.750746
let C(20) = 6.24317e-4
let C(21) = -7.75655e+6
let C(22) = 104371.
let C(23) = -523.659
let C(24) = 1.1613
let C(25) = -9.60695e-4

DEF f1(x,z)=1
DEF f2(x,z)=X
DEF f3(x,z)=X^2
DEF f4(x,z)=X^3
DEF f5(x,z)=X^4
DEF f6(x,z)=log(z/x)
DEF f7(x,z)=log(z/x)*X
DEF f8(x,z)=log(z/x)*X^2
DEF f9(x,z)=log(z/x)*X^3
DEF f10(x,z)=log(z/x)*X^4
DEF f11(x,z)=(log(z/x))^2
DEF f12(x,z)=((log(z/x))^2)*X
DEF f13(x,z)=((log(z/x))^2)*X^2
DEF f14(x,z)=((log(z/x))^2)*X^3
DEF f15(x,z)=((log(z/x))^2)*X^4
DEF f16(x,z)=(log(z/x))^3
DEF f17(x,z)=((log(z/x))^3)*X
DEF f18(x,z)=((log(z/x))^3)*X^2
DEF f19(x,z)=((log(z/x))^3)*X^3
DEF f20(x,z)=((log(z/x))^3)*X^4
DEF f21(x,z)=(log(z/x))^4
DEF f22(x,z)=((log(z/x))^4)*X
DEF f23(x,z)=((log(z/x))^4)*X^2
DEF f24(x,z)=((log(z/x))^4)*X^3
DEF f25(x,z)=((log(z/x))^4)*X^4
```

```
  let i=1
  let x1(1)=T
  let x2(1)=Tsat

  LET f(i,1)=f1(X1(i),X2(i))
  LET f(i,2)=f2(X1(i),X2(i))
  LET f(i,3)=f3(X1(i),X2(i))
  LET f(i,4)=f4(X1(i),X2(i))
  LET f(i,5)=f5(X1(i),X2(i))
  LET f(i,6)=f6(X1(i),X2(i))
  LET f(i,7)=f7(X1(i),X2(i))
  LET f(i,8)=f8(X1(i),X2(i))
  LET f(i,9)=f9(X1(i),X2(i))
  LET f(i,10)=f10(X1(i),X2(i))
  LET f(i,11)=f11(X1(i),X2(i))
  LET f(i,12)=f12(X1(i),X2(i))
  LET f(i,13)=f13(X1(i),X2(i))
  LET f(i,14)=f14(X1(i),X2(i))
  LET f(i,15)=f15(X1(i),X2(i))
  LET f(i,16)=f16(X1(i),X2(i))
  LET f(i,17)=f17(X1(i),X2(i))
  LET f(i,18)=f18(X1(i),X2(i))
  LET f(i,19)=f19(X1(i),X2(i))
  LET f(i,20)=f20(X1(i),X2(i))
  LET f(i,21)=f21(X1(i),X2(i))
  LET f(i,22)=f22(X1(i),X2(i))
  LET f(i,23)=f23(X1(i),X2(i))
  LET f(i,24)=f24(X1(i),X2(i))
  LET f(i,25)=f25(X1(i),X2(i))

  MAT yc=f*C
  let sSHV=yc(1)

end def


Def Mdvap(P,Td,dp)
   !Suction mass flow rate (lb/hr)
   Declare def rhoSHV,T

   let Tsat=T(P)
   let Tsuper=Td-Tsat
   let dens=rhoshv(Tsuper,Tsat)*.062428          !lb/ft^3
   if dp<-.015 then
     let Mdvap=-(48.487+416.13*sqr((dp+.015)*dens))
   else
     let Mdvap=48.487+416.13*sqr((dp+.015)*dens)
   end if

end Def

Def Mddisch(P,Td,dp)
   !Discharge mass flow rate (lb/hr)
```

```
   Declare def rhoSHV,T

   let Tsat=T(P)
   let Tsuper=Td-Tsat
   let dens=rhoshv(Tsuper,Tsat)*.062428          !lb/ft^3
   if dp<-.04 then
     let Mddisch=-(-70.561+280.78*sqr((dp+.04)*dens))
   else
     let Mddisch=-70.561+280.78*sqr((dp+.04)*dens)
   end if

end Def

Def Mdliq(T,dp)
   !Liquid mass flow rate (lb/hr)
   declare def Densliq
   let dens=Densliq(T)
   let dens=dens*.062428                    !lb/ft^3
   if dp<-0.007 then
     let Mdliq=-67.0537*sqr((abs(dp)+.007)*dens)
   else
     let Mdliq=67.0537*sqr((dp+.007)*dens)
   end if

end Def
```

APPENDIX B

Component Model Developer

TrueBasic™ Version 2.02

Modified on Macintosh IIx

```
dim dependent(1,1),independent(1,1),yd(1),id$(20),prev(20)
dim xn(1,1),xn1(1,1),wni(1,1),wi(1,1),zn(1,1),zn1(1,1),bnte(1,1)
dim bn(1,1),bn1(1,1),t(20),tt(1),bnt(1,1),inda(1)

let indmax=10
let nwst$="y"
do while nwst$<>"n"
  input prompt "Sound with result? ":snd$
  let snd$=lcase$(snd$[1:1])
  input prompt "Ambient pressure [inches Hg]? ":hpsi
  let ppsi=hpsi*0.491154077497
  call indat(kft,lagt,dependent,independent,snd$,indmax)
  let lagt=-abs(lagt)
  let new$="y"
  let indep$="y"

  do while new$<>"n"
    let n=0
    print
    input prompt "Time interval? ":stp
    let kf=int(kft/stp)
    let lag=int(lagt/stp)
    call varlist
    call dselect(kf,lag,stp,d$,dependent,independent,yd)

    let newind$="y"
    call
indselect(n,kf,lag,stp,id$,d$,prev,ind,inda,independent,bn,bn1,xn,xn1,yd,no,newind$,a
uto$,indmax,man)

    do while newind$<>"n"
      if man<>1 then
        if auto$="y" then
          call
auto(n,kf,lag,stp,ind,inda,no,ssen,msen,prev,independent,yd,xn,xn1,zn,zn1,bn,bn1,wi,
wni,id$,d$,indmax)
        end if
        let mank=0
         call x1(kf,prev(n+1),stp,ind,d$,xn1,independent)

        if n<>0 and man<>1 then
            call winv(n,kf,stp,xn,xn1,yd,wni,wi,zn,zn1,bn1,bn,no)
```

```
          call ftest(n+1,kf,stp,yd,inda,prev,independent,bn1,f,msen1,ssen,ssen1,d$)
         call ttest(n,msen1,bn1,wi,t)
        else
          call
first(kf,stp,prev(n+1),ind,inda,xn1,independent,yd,zn,wni,bn,bn1,ssen1,msen,msen1,d$
)
          mat xn=xn1
          mat wi=wni
          call ttest(n,msen1,bn1,wi,t)
        end if
      else
        let newind$="n"
         call ftest(n,kf,stp,yd,inda,prev,independent,bn1,f,msen1,ssen,ssen1,d$)
        mat bn=bn1
        let ind=inda(n)
        let n=n-1
        let mank=1
      end if

      call
result(n,kf,lag,stp,id$,prev,d$,bn,bn1,f,t,msen,msen1,ssen,ssen1,ft,tt,msent,msen1t,bnt
,bnte,snd$,xn,xn1,yd,independent,ind,inda,man)
      if mank<>1 then
        call varlist
        call
indselect(n,kf,lag,stp,id$,d$,prev,ind,inda,independent,bn,bn1,xn,xn1,yd,no,newind$,a
uto$,indmax,man)
      else
        let newind$="n"
      end if
    loop

    if n<>0 then call
keep(n,kf,stp,lag,id$,prev,d$,bnt,bn1,f,t,msent,msen1t,yd,xn,independent,inda,mank)
    print
    input prompt "Try new dependent variable? ":new$
    let new$=new$[1:1]
    let new$=lcase$(new$)
    clear
  loop
  input prompt "Run new data set? ":nwst$
  let nwst$=nwst$[1:1]
  let nwst$=lcase$(nwst$)
loop


end


Sub
first(kf,stp,i,ind,inda(),xn(,),independent(,),yd(),zn(,),wni(,),bn(,),bn1(,),ssen1,msen,m
sen1,d$)
   dim bnz(1,1),wn(1,1),bnt(1,1),xnt(1,1),yc(1,1),pre(1)
  mat zn=zer(1,1)
```

```
 mat wn=zer(1,1)
 let pre(1)=i

 for k=1 to kf
    let wn(1,1)=wn(1,1)+xn(k,1)^2
    let zn(1,1)=zn(1,1)+yd(k)*xn(k,1)
 next k

 mat wni=inv(wn)
 mat bn=wni*zn
 mat bn1=bn

 let ssen1=0

 call model(yc,bn1,1,kf,stp,inda,independent,pre,d$)
 for k=1 to kf
   let ssen1=ssen1+(yc(1,k)-yd(k))^2
 next k

 let msen1=ssen1/(kf-1)
 let msen=msen1
end sub

Sub  winv(n,kf,stp,xn(,),xn1(,),yd(),wni(,),wi(,),zn(,),zn1(,),bn1(,),bn(,),no)
   dim cw(1,1),d(1,1),dt(1,1),ddt(1,1),a(1,1),g(1,1),xnxn1(1,1)
   dim gt(1,20),gwg(1,1),gw(1,20),zp(20,1),yxn(20,1),tempx(1,1)

 let h=0
 if n>1 and no<>n then
   mat wni=wi
   mat zn=zn1
 end if
 let no=n
 mat g=zer(n,1)
 mat gt=zer(1,n)
 mat gw=zer(1,n)
 mat xnxn1=zer(n,1)
 mat cw=zer(n,n)
 mat d=zer(n,1)
 mat dt=zer(1,n)
 mat ddt=zer(n,n)
 mat a=zer(n,n)
 mat zp=zer(n,1)
 mat yxn=zer(n,1)
 mat zn1=zer(n+1,1)

 for k=1 to kf
   for i=1 to n
      let xnxn1(i,1)=xnxn1(i,1)+xn(k,i)*xn1(k,1)
      let yxn(i,1)=yxn(i,1)+yd(k)*xn(k,i)
   next i
   let h=h+xn1(k,1)^2
   let zn1(n+1,1)=zn1(n+1,1)+yd(k)*xn1(k,1)
 next k
```

```
    mat zp=yxn
    mat g=xnxn1
    mat gt=trn(g)
    mat gw=gt*wni
    mat gwg=gw*g
    let hdif=h-gwg(1,1)
    if hdif=0 then let hdif=.001
    let c=1/(hdif)
    mat cw=(-c)*wni
    mat d=cw*g
    mat dt=trn(d)
    mat ddt=d*dt
    mat ddt=(c^(-1))*ddt
    mat a=ddt+wni
    mat wi=zer(n+1,n+1)

    for i=1 to n
       for j=1 to n
          let wi(i,j)=a(i,j)
          let zn1(j,1)=zp(j,1)
       next j
       let wi(n+1,i)=d(i,1)
       let wi(i,n+1)=d(i,1)
    next i

    let wi(n+1,n+1)=c
    mat bn1=wi*zn1
end sub

sub ftest(n,kf,stp,yd(),inda(),prev(),independent(,),bn1(,),f,msen1,ssen,ssen1,d$)
    dim yc(1,1)

    let ssen1=0
    call model(yc,bn1,n,kf,stp,inda,independent,prev,d$)

    for k=1 to kf
       let ssen1=ssen1+(yc(1,k)-yd(k))^2
    next k

    let f=(ssen-ssen1)*(kf-n-1)/ssen1
    let msen1=ssen1/(kf-n-1)
end sub

sub ttest(n,msen1,bn1(,),wi(,),t())
    for var=1 to n+1
       let t(var)=abs(bn1(var,1)/(msen1*wi(var,var)))
    next var
end sub

sub x1(kf,i,stp,ind,d$,xn1(,),independent(,))
    mat xn1=zer(kf,1)
    if ind<>8 then
      for k=1 to kf
```

```
      let xn1(k,1)=independent((k-i)*stp,ind)
    next k
  else
    for k=1 to kf
      let xn1(k,1)=1
    next k
  end if

!   if d$="Pcond" and (ind=1 or ind=9) then
!     for k=1 to kf
!       let xn1(k,1)=1/independent((k-i)*stp,ind)
!     next k
!   end if
!   if d$="Power" and (ind=1 or ind=9) then
!     for k=1 to kf
!       let xn1(k,1)=1/independent((k-i)*stp,ind)
!     next k
!   end if

end sub

sub
auto(n,kf,lag,stp,ind,inda(),no,ssen,msen,prev(),independent(,),yd(),xn(,),xn1(,),zn(,),z
n1(,),bn(,),bn1(,),wi(,),wni(,),id$(),d$,indmax)
   dim fs(1),max(4),t(1),maxt(3),tot(1,1)
  mat t=zer(n+1)
  mat maxt=zer(3)
  mat tot=zer(indmax-1,3)
  let indt=ind

  if indt=indmax then
    let all=indmax-1
  else
    let all=1
  end if

  for var=1 to all
     let max(1)=-1e6
     if indt=indmax then
       let ind=var
       let inda(n+1)=var
       if var=7 then
         let prev(n+1)=1
       else
         let prev(n+1)=0
       end if
     end if
     if ind<>7 then
       let l=0
       let intr=-lag
     else
       let l=1
       let intr=-lag-1
     end if
```

```
let intrt=intr
do while intr>10
  let j=0
  let max(1)=0
  let rint=round(intr/10)
  mat fs=zer(round(intr/rint+.5))

  for i=l to l+intr step rint
    let j=j+1
     call x1(kf,i,stp,ind,d$,xn1,independent)
    if n<>0 then
      let prev(n+1)=i
        call winv(n,kf,stp,xn,xn1,yd,wni,wi,zn,zn1,bn1,bn,no)
        call ftest(n+1,kf,stp,yd,inda,prev,independent,bn1,f,msen1,ssen,ssen1,d$)
    else
      call
first(kf,stp,i,ind,inda,xn1,independent,yd,zn,wni,bn,bn1,ssen1,msen,msen1,d$)
      let f=1/sqr(abs(msen1))
    end if
    let fs(j)=f
    if f>max(1) then
      let max(1)=f
      let max(2)=j
      let max(3)=i
      let max(4)=msen1
    end if
  next i

  if max(2)>1 and max(2)<j-1 then
    let l=max(3)-rint+1
    let intr=2*rint-2
  else
    if rint>(-lag-max(3)) then
      let l=max(3)-rint+1
      let intr=rint+(-lag-max(3))-1
    else
      let l=max(3)
      let intr=rint-1
    end if
  end if
  print
  call indlabel(ind,d$,label$)
  print label$;
  print " test trend:"
  mat print fs
loop

let j=0
mat fs=zer(round(intr+.5))
for i=l to l+intr
  let j=j+1
  call x1(kf,i,stp,ind,d$,xn1,independent)
  if n<>0 then
    let prev(n+1)=i
```

```
            call winv(n,kf,stp,xn,xn1,yd,wni,wi,zn,zn1,bn1,bn,no)
            call ftest(n+1,kf,stp,yd,inda,prev,independent,bn1,f,msen1,ssen,ssen1,d$)
         else
           call
 first(kf,stp,i,ind,inda,xn1,independent,yd,zn,wni,bn,bn1,ssen1,msen,msen1,d$)
           let f=1/sqr(abs(msen1))
         end if
         let fs(j)=f
         if f>max(1) then
           let max(1)=f
           let max(3)=i
           let max(4)=msen1
         end if
       next i

       if intrt<10 then
         print
         call indlabel(ind,d$,label$)
         print label$;
         print " test trend:"
         mat print fs
       end if
       if indt=indmax then
         let tot(var,1)=max(1)
         let tot(var,2)=max(3)
         let tot(var,3)=max(4)
         if max(1)>maxt(1) then
           let maxt(1)=max(1)
           let maxt(2)=max(3)
           let maxt(3)=var
         end if
         let max(3)=maxt(2)
       end if
   next var
   if indt=indmax then
     let ind=maxt(3)
     let inda(n+1)=ind
     call autodisp(n,ind,tot,d$,id$)
   end if
   let prev(n+1)=max(3)
end sub

sub autodisp(n,ind,tot(,),d$,id$())
   let form$="#########     ###     #######.##     ####.#"
   print
   print "Maximum criteria values for each independent variable:"
   print
   print " Variable      Lag       ";
   if n<>0 then
     print "   F          ";
   else
     print "  1/std       ";
   end if
   print "Std"
```

```
    print
    print using form$:"Ncomp",tot(1,2),tot(1,1),sqr(abs(tot(1,3)))
    print using form$:"Krvi",tot(2,2),tot(2,1),sqr(abs(tot(2,3)))
    print using form$:"Pd/Ps",tot(3,2),tot(3,1),sqr(abs(tot(3,3)))
    print using form$:"vddis",tot(4,2),tot(4,1),sqr(abs(tot(4,3)))
    print using form$:"Trci",tot(5,2),tot(5,1),sqr(abs(tot(5,3)))
    print using form$:"Taci",tot(6,2),tot(6,1),sqr(abs(tot(6,3)))
    print using form$:"Nc^2",tot(9,2),tot(9,1),sqr(abs(tot(9,3)))
    print using form$:"Constant",tot(8,2),tot(8,1),sqr(abs(tot(8,3)))
    print using form$:d$,tot(7,2),tot(7,1),sqr(abs(tot(7,3)))
    print
    call indlabel(ind,d$,id$(n+1))
end sub

sub varlist
   print
   print
   print "    Dependent Variables","  Independent Variables"
   let form$="          ############             ###################"
   print
   print using form$:"vdots [v]","Ncomp [nc]"
   print using form$:"Power [po]","Krvi [v]"
   print using form$:"Pcond [pc]","Pd/Ps [pr]"
   print using form$:"Pevap [pe]","vdots [f]"
   print using form$:"Teao [t]","Trci [r]"
   print using form$:"  ","Taci [i]"
   print using form$:"  ","Nc^2 [2]"
   print using form$:"  ","Constant [c]"
   print using form$:"  ","Dependent [d]"
   print using form$:"  ","Auto [a]"
   print using form$:"  ","Model check [m]"
   print using form$:"  ","None [n]"
   print
   print
end sub

sub dselect(kf,lag,stp,d$,dependent(,),independent(,),yd())
   let dep=0
   mat yd=zer(lag+1:kf)

   do while dep=0
      input prompt "Select dependent variable: ":dvar$
      let dvar$=lcase$(dvar$)
      if dvar$[1:1]="t" then let dep=3
      if dvar$[1:2]="po" then let dep=4
      if dvar$[1:2]="pc" then let dep=1
      if dvar$[1:2]="pe" then let dep=2
      if dvar$[1:1]="v" then let dep=5
      if dep=0 then print "Not a valid variable"
   loop

   if dep=1 then let d$="Pcond"
   if dep=2 then let d$="Pevap"
   if dep=3 then let d$="Teao"
```

```
  if dep=4 then let d$="Power"
  if dep=5 then let d$="vdots"

  for k=lag+1 to kf
     let yd(k)=dependent(k*stp,dep)
     let independent(k*stp,7)=yd(k)
  next k

  print
end sub

sub
indselect(n,kf,lag,stp,id$(),d$,prev(),ind,inda(),independent(,),bn(,),bn1(,),xn(,),xn1(,),
yd(),no,newind$,auto$,indmax,man)
   dim tempx(1,1),tempi(1),tempb(1,1),yc(1,1),bnt(1,1),xnt(1,1)
  let man$="y"

  if man<>1 then
    if n=0 then
      mat xn=zer(kf,1)
      mat bn1=zer(1,1)
      mat bn=zer(1,1)
    end if

    if n<>0 and no<>n then
      mat tempx=zer(kf,n-1)
      mat tempx=xn
      mat xn=zer(kf,n)

      for k=1 to kf
         for i=1 to n-1
            let xn(k,i)=tempx(k,i)
         next i
         let xn(k,n)=xn1(k,1)
      next k
    end if
  end if

  mat xn1=zer(kf,1)
  let man=0

  do while man$="y"
    let ind=0

    do while ind=0
      input prompt "Select independent variable (or None): ":indvar$
      let indvar$=lcase$(indvar$)
      if indvar$[1:1]="n" then let ind=99
      if indvar$[1:1]="d" then let ind=7
      if indvar$[1:1]="c" then let ind=8
      if indvar$[1:1]="a" then let ind=indmax
      if indvar$[1:2]="nc" then let ind=1
      if indvar$[1:1]="v" then let ind=2
      if indvar$[1:2]="pr" then let ind=3
```

```
    if indvar$[1:1]="f" then let ind=4
    if indvar$[1:1]="r" then let ind=5
    if indvar$[1:1]="i" then let ind=6
    if indvar$[1:1]="2" then let ind=9
    if indvar$[1:1]="m" then
      let man=1
      let n=0
      print
      print
      print "Enter model:"
      print
    else
      if ind=0 then
        print "Not a valid variable"
      end if
    end if
 loop

 if man<>1 or ind=99 then let man$="n"

 if ind<>99 then
   mat tempi=inda
   mat inda=zer(n+1)
   for i=1 to n
      let inda(i)=tempi(i)
   next i
   let inda(n+1)=ind
 end if

 if ind<>99 and ind<>indmax then
   let prev(n+1)=1e6


   do while prev(n+1)>-lag
     if ind<>7 and ind<>8 then
       print "Select lag ( 0 -";-lag;
       input prompt ") or Auto: ":in$
     else
       if ind=7 then
         print "Select lag ( 1 -";-lag;
         input prompt ") or Auto: ":in$
       end if
     end if
     let in$=lcase$(in$)
     if ord(in$[1:1])>47 and ord(in$[1:1])<58 then
       let prev(n+1)=val(in$)
       let prev(n+1)=abs(prev(n+1))
       let auto$="n"
     else
       if ind<>8 then
         let auto$="y"
         let prev(n+1)=1
       else
         let auto$="n"
```

```
              let prev(n+1)=0
           end if
        end if
      loop

    end if


    if ind<>99 then
      call indlabel(ind,d$,id$(n+1))
      if ind=indmax then let auto$="y"
      if man=1 then
        mat tempb=bn1
        mat bn1=zer(n+1,1)
        for i= 1 to n
          let bn1(i,1)=tempb(i,1)
        next i
        print
        input prompt "Coefficient = ":bn1(n+1,1)
        print
      end if
    else
      if man<>1 then let newind$="n"
    end if
    if man$="y" then let n=n+1
  loop

end sub

sub indlabel(ind,d$,label$)
  if ind=1 then let label$="Ncomp"
  if ind=2 then let label$="Krvi"
  if ind=3 then let label$="Pd/Ps"
  if ind=4 then let label$="vdots"
  if ind=5 then let label$="Trci"
  if ind=6 then let label$="Taci"
  if ind=9 then let label$="Nc^2"
  if ind=7 then let label$=d$
  if ind=8 then let label$="Const"
end sub

sub indat(kf,lag,dependent(,),independent(,),snd$,indmax)
  dim temp(1,54),label$(54)

  input prompt "Data file? ":data$
  let data$=data$&".table"
  open #1:name data$, access input, org text
  input #1: kf
  input #1: lag
  print "Number of time steps (<";kf;
  input prompt ")? ":kf
  print "Number of previous steps available (<";lag;
  input prompt ")? ":lag
  let kf=kf-lag
```

```
  let lag=-lag
  print
  print "           Processing data..."
  mat dependent=zer(lag+1:kf,5)
  mat independent=zer(lag+1:kf,indmax-1)
  mat input #1:label$
  print tab(12,20); "Minutes Remaining:"

  for k=lag+1 to kf
     if k=lag+1 then let t1=time
     mat input #1:temp
     let independent(k,1)=temp(1,24)                    !Ncomp
     let independent(k,2)=temp(1,39)                    !Krvi
     let independent(k,3)=(temp(1,23)+ppsi)/(temp(1,21)+ppsi)  !Kpr
     let independent(k,4)=(temp(1,41)*temp(1,39))          !vdots
     let independent(k,5)=temp(1,5)                    !Trci
     let independent(k,6)=temp(1,24)^2                   !Nc^2
     let independent(k,8)=1                          !Constant
     let independent(k,9)=1/temp(1,2)                   !Taci

     let dependent(k,1)=temp(1,6)                      !Pci
     let dependent(k,2)=temp(1,18)                      !Peo
     let dependent(k,3)=temp(1,12)                      !Teao
     let dependent(k,4)=temp(1,46)                      !Power
     let dependent(k,5)=(temp(1,41)*temp(1,39))             !vdots

     if k=lag+1 then let t2=time
     if k=lag+1 or k/10=int(k/10) then
       print tab(12,38);"        "
       print tab(12,38); round((kf-k)*(t2-t1)/60,2)
     end if
  next k

  close #1
  if snd$="y" then call beep
end sub

sub beep
  sound 750,.075
end sub

sub
result(n,kf,lag,stp,id$(),prev(),d$,bn(,),bn1(,),f,t(),msen,msen1,ssen,ssen1,ft,tt(),msent,
msen1t,bnt(,),bnte(,),snd$,xn(,),xn1(,),yd(),independent(,),ind,inda(),man)
  dim xtp(1,1)
  let form$=" ###########    ###   -#.####^^^^  -#.####^^^^    -#.##^^^^"
  let form1$=" ###########    ###          -#.####^^^^"
  print
  print "Dependent Variable: ";d$
  print
  print "Step:";stp
  print
  print "                     Coefficients"
```

```
if man<>1 then
  print " Variable      Lag      Old      New      t"
else
  print " Variable      Lag"
end if

print

if n<>0 and man<>1 then
   for i=1 to n
      print using form$: id$(i),prev(i),bn(i,1),bn1(i,1),t(i)
   next i
else
   if man=1 then
     for i=1 to n
        print using form1$: id$(i),prev(i),bn1(i,1)
     next i
   end if
end if
if man<>1 then
   print using form$: id$(n+1),prev(n+1),"-----",bn1(n+1,1),t(n+1)
else
   print using form1$: id$(n+1),prev(n+1),bn1(n+1,1)
end if

print
print
print " n(old) = ";n
print " n(new) = ";n+1

if n<>0 and man<>1 then
   print "     F = ";f
   print "  SD(n) = ";sqr(msen)
end if

print "SD(n+1) = ";sqr(msen1)
print "Degrees of Freedom: ";kf-n-1
print
if snd$="y" then call beep
input prompt "See graph? ":ans$
let ans$=lcase$(ans$[1:1])
if ans$="y" or ans$="m" then call
graph(n,kf,stp,lag,prev,bn,bn1,xn,xn1,yd,d$,ans$,inda,independent,man)
let n=n+1
if man<>1 then
  input prompt "Retain this variable? ":ans$
  let ans$=lcase$(ans$[1:1])
  if ans$="y" then
    let ft=f
    let ssen=ssen1
    let msent=msen
    let msen=msen1
    let msen1t=msen1
    mat tt=t
```

```
        mat bnt=bn
        mat bn=bn1
        mat bnte=bn1
      else
        let f=ft
        let n=n-1
        if n<>0 then mat t=tt
        mat bn1=bnte
      end if
    end if
end sub

sub
keep(n,kf,stp,lag,id$(),prev(),d$,bn(,),bn1(,),f,t(),msen,msen1,yd(),xn(,),independent(,)
,inda(),man)
   dim bn1t(1,1),yc(1,1),xnt(1,1)
   let form$=" ###########    ###    -#.####^^^   -#.####^^^     -#.##^^^"
   let form1$=" ###########    ###          -#.####^^^"
   print
   input prompt "Save results? ":save$
   let save$=lcase$(save$)
   if save$="y" then
     input prompt "Save Coefficients or Fit data (or Both)? ":type$
     let type$=lcase$(type$[1:1])
     input prompt "Name of file: ":file$
     if type$="c" or type$="b" then
        open #2:name file$&".coef", create "newold"
        erase #2
        print #2:
        print #2: "Dependent Variable: ";d$
        print #2:
        print #2: "Step:";stp
        print #2:
        print #2: "                    Coefficients"
        if man<>1 then
          print #2: " Variable       Lag       Old       New       t"
        else
          print #2: " Variable       Lag"
        end if

        print

        if n<>0 and man<>1 then
           for i=1 to n-1
              print #2, using form$: id$(i),prev(i),bn(i,1),bn1(i,1),t(i)
           next i
        else
           if man=1 then
             for i=1 to n-1
                print #2, using form1$: id$(i),prev(i),bn1(i,1)
             next i
           end if
        end if
        if man<>1 then
```

```
        print #2, using form$: id$(n),prev(n),"-----",bn1(n,1),t(n)
      else
        print #2, using form1$: id$(n),prev(n),bn1(n,1)
      end if

      print #2:
      print #2:
      print #2: " n(old) = ";n-1
      print #2: " n(new) = ";n

      if n>1 and man<>1 then
        print #2: "     F = ";f
        print #2: "  SD(n) = ";sqr(msen)
      end if

      print #2: "SD(n+1) = ";sqr(msen1)
      print #2: "Degrees of Freedom: ";kf-n
      print #2:
      close #2
    end if
    if type$="f" or type$="b" then
      open #2:name file$&".fit", create "newold"
      erase #2

      if d$[1:1]="P" then let unit$="  (psig)"
      if d$[1:2]="Po" then let unit$="  (Btu/hr)"
      if d$[1:1]="S" or d$[1:1]="T"  then let unit$="  (°F)"
      if d$[1:1]="R" then let unit$="  (%)"

      print #2:"Time  (sec),";d$&unit$;",Predicted,Ncomp,Tcai,Teai,Vdac,Vdae,Rhei"

      call model(yc,bn1,n,kf,stp,inda,independent,prev,d$)
      for k=lag+1 to 0
        print #2: k*stp;",";yd(k);",";",";independent(k*stp,1);",";
        print #2:
independent(k*stp,2);",";independent(k*stp,3);",";independent(k*stp,4);",";
        print #2: independent(k*stp,5);",";independent(k*stp,6)
      next k
      for k=1 to kf
        print #2: k*stp;",";yd(k);",";yc(1,k);",";independent(k*stp,1);",";
        print #2:
independent(k*stp,2);",";independent(k*stp,3);",";independent(k*stp,4);",";
        print #2: independent(k*stp,5);",";independent(k*stp,6)
      next k

      close #2
    end if
  end if
end sub

sub
graph(n,kf,stp,lag,prev(),bn(,),bn1(,),xn(,),xn1(,),yd(),d$,ans$,inda(),independent(,),m
an)
  dim bnt(1,1),bn1t(1,1),yc(1,1),yb(1,1),xnt(1,1),xn1t(1,1),vplot(1,2),tempx(1,1)
```

```
mat yb=zer(1,kf)
let tme=kf*stp
open #3: screen .55,1,.02,.52
ask pixels px,py
call model(yc,bn1,n+1,kf,stp,inda,independent,prev,d$)
if man<>1 then call model(yb,bn,n,kf,stp,inda,independent,prev,d$)
let maxind=0
let minind=yd(1)
for k=1 to kf
   if yc(1,k)>maxind then let maxind=yc(1,k)
   if yd(k)>maxind then let maxind=yd(k)
   if yc(1,k)<minind then let minind=yc(1,k)
   if yd(k)<minind then let minind=yd(k)
next k
if maxind=int(maxind) then let maxind=maxind+.1
let morder=pos(str$(maxind),".")-2
let maxind=round(maxind+.5*10^morder,-morder)
if ans$="m" then
   let minorder=pos(str$(minind),".")-2
   let minind=round(minind-.5*10^minorder,-minorder)
   if (maxind-minind)/(10^(morder))<2 then let morder=morder-1
else
   let minind=0
end if
let order=len(str$(tme))-1
let tme=round(tme+.5*10^order,-order)
set window 0,tme,minind,maxind
plot lines:0,maxind;0,minind;tme,minind
let max=(maxind-minind)/(10^(morder))
for i=1 to max
   plot lines: 0,i*(10^(morder))+minind;.01*tme,i*(10^(morder))+minind
next i
let max=tme/(10^(order))
for i=1 to max
   plot lines: i*(10^(order)),minind;i*(10^(order)),.01*(maxind-minind)+minind
next i
mat vplot=zer(kf,2)
for k=1 to kf
   let vplot(k,1)=k*stp
   let vplot(k,2)=yd(k)
next k
plot text, at .8*tme,(.0625+.025*426/py)*(maxind-minind)+minind : d$
mat plot lines: vplot
if n<>0 then
   for k=1 to kf
      let vplot(k,2)=yb(1,k)
   next k
   set color "red"
   mat plot lines: vplot
   plot text, at .8*tme,.0625*(maxind-minind)+minind : "Previous"
end if
for k=1 to kf
   let vplot(k,2)=yc(1,k)
next k
```

```
   set color "blue"
   if n<>0 then
     plot text, at .8*tme,(.0625-.025*426/py)*(maxind-minind)+minind : "New"
   else
     plot text, at .8*tme,.0625*(maxind-minind)+minind : "New"
   end if
   mat plot lines: vplot
   set color "black"
   plot text, at .5*tme,.975*(maxind-minind)+minind : d$
   plot text, at .1*tme,(.0625+.0125*426/py)*(maxind-minind)+minind : "x: 0 -
"&str$(tme)
   plot text, at .1*tme,(.0625-.0125*426/py)*(maxind-minind)+minind : "y:
"&str$(minind)&" - "&str$(maxind)
   get key z
   clear
   close #3
end sub


sub model(yc(,),bn1(,),n,kf,stp,inda(),independent(,),prev(),d$)
   dim bnt(1,1),indp(1,1),temp(1,1)

   mat indp=zer(kf,n)
   mat yc=zer(1,kf)

   for i=1 to n
        call x1(kf,prev(i),stp,inda(i),d$,temp,independent)
        for k=1 to kf
          let indp(k,i)=temp(k,1)
        next k
   next i


   for k=1 to kf
      for i=1 to n
         if inda(i)<>7 then
            let yc(1,k)=yc(1,k)+bn1(i,1)*indp(k,i)
         else
           if k>prev(i) then
              let yc(1,k)=yc(1,k)+bn1(i,1)*yc(1,(k-prev(i)))
           else
              let yc(1,k)=yc(1,k)+bn1(i,1)*independent((k-prev(i))*stp,7)
           end if
         end if
      next i
   next k

end sub
```